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Long Range Program of Systematic Geologic Exploration of the Moon

by

Thor N. V. Karlstrom
and others

U.S. Geological Survey

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LONG RANGE PROGRAM OF SYSTEMATIC GEOLOGIC EXPLORATION OF THE MOON

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LONG RANGE PROGRAM OF SYSTEMATIC GEOLOGIC EXPLORATION OF THE MOON

INTRODUCTION

For the first time in history man has developed a technological capability to travel in space and to study on the ground or at close range near-by planetary bodies. The anticipated returns from such planetary missions are largely, if not entirely scientific in nature. The enormous cost of space travel makes it unlikely that new mineral resources will be discovered on other planets that can be economically returned for man's use on earth. The planetary environments, as presently known make it unlikely that any of the planetary bodies can be used for future mass colonization by man. Thus any realistic program for space exploration must emphasize the potential returns in scientific information and technological developments and on planning that will optimize the quality and quantity of scientific data returned with the fewest number of costly missions. Our present national effort to place a man on the moon will likely be judged by future generations not so much on who lands there first, but on the demonstrated effectiveness of a continuing scientific program designed to systematically probe the mysteries of the larger world about us.

The immediate major scientific goal in space is the geologic exploration of the moon, primarily because it is the closest hardsurface planetary body to the earth (Space Science Board, 1965, p. 19-32). The major scientific questions to be answered about the moon relate to its physical composition, environment, and history, and are thus fundamentally geologic in character. Their solution primarily involves geologic analyses of the lunar rock types, their structural and stratigraphic relations at the surface and at depths, and of the endogenetic and exogenetic processes that have shaped the lunar landscape. Knowledge of the physical character of the moon is thus indispensable as an initial step in a progressive analysis of the geologic record of the origin and evolution of the planets in the solar system, a study which the National Academy of Sciences (Space Science Board, 1965, p. 1) has proposed as one of this generation's central scientific problems.

A comprehensive 10 year lunar exploration program designed to meet basic scientific objectives has been proposed by the Geology Working Group of the NASA 1965 Falmouth Conference on Lunar Exploration and Science (1965). This paper briefly summarizes the major conceptual elements involved in such a program, and discusses the current status of geologic research and planning essential to the development of typical scientific mission profiles for lunar areas, examples of which are included in the appendix.

MAIN ELEMENTS IN PLANNING AND IMPLEMENTING A LONG RANGE LUNAR EXPLORATION PROGRAM

The main elements in planning and implementation include:

1. Geologic evaluation in depth of available lunar data, largely photographic, as a basis for selecting suitable landing sites in areas that are most likely to provide the surface and subsurface data bearing directly on current interpretations of lunar geology.

2. Detailed planning of ground traverses, procedures, and instrumentation, tailored to the hostile lunar environment, to local terrain conditions, and to specified scientific objectives for each selected area.

3. Retention of program flexibility to accommodate schedule changes and shifts in scientific emphasis required by data obtained during succeeding missions.

Under the most ambitious scheduling of manned exploration missions, only a small fraction of the lunar surface will be mapped and observed on the ground. This central fact dictates the most careful selection of manned landing sites, as well as extension of this ground control into an adequate geographic grid of information by use of automated landing systems, remote sensing probes, and photography, if fundamental problems of lunar geology are to be solved.

Full integration of manned and unmanned missions is therefore required during early phases of planning in developing a comprehensive post-early Apollo exploration program designed to satisfy geologic and other scientific objectives.

PLANNING FOR SPECIFIC MANNED MISSIONS

Geologic Selection of Surface Exploration Sites

Geologic mapping of the moon based on telescopic, Ranger, Surveyor, and Lunar Orbiter photography has delineated potential landing areas and numerous geologic problems that can be solved by well designed manned missions. Smoother mare areas within the equatorial belt of the near side of the moon have been selected as suitable for early Apollo Landings from the analysis of high resolution photography of the Lunar II and III missions. Surveyor I and III results combined with the Lunar Orbiter regional data indicate that surface roughness, not bearing strength, of lunar surface materials is the main limiting factor in landing site selections over much of the moon.

Numerous mare landing sites of the early Apollo type are also available outside of the equatorial belt in the extensive mare areas of the near side of the moon, and in the more restricted mare areas on the far side of the moon. A comprehensive geologic program of manned exploration could be developed by landings restricted to mare areas and by use of long range mobile ground vehicles that would permit traversing beyond mare margins into highland and large crater areas of critical geologic significance. However, increased design capabilities for landing in rougher terrain or in small smooth areas in uplands is required for most efficient scientific surface exploration and data collection.

Geologic coverage of the near side of the moon is sufficiently advanced to provide confidence in the selection of the most critical areas and features for geologic analysis during manned surface operations. Geologic mapping from Orbiter IV photography of the far side of the moon is now in progress, and will lead to additional geologic site selections. Continuous upgrading of the lunar geological maps, extensions in areal coverage and at larger scales of presentation of lunar features and materials are essential for planning operations and possible redirections during progressive phases of the exploration program.

The following geologic sites have been selected as possible candidates for manned surface operations and for preparation of preliminary scientific mission profiles: Crater Copernicus (classic example of a larger young crater of impact origin); Crater Alphonsus (with floor and wall features of either impact or volcanic origin; possibly a site of recent volcanic activity); The Aristarcus Plateau (of possible volcanic origin); highly cratered, rugged area near North Pole (area in which latitudinal changes in temperature regimen may be detected in material or surface weathering conditions, and in the form of permafrost at shallow depths*); and Flamsteed Structure (either an old crater rim,

*Analyses of ground ice that may be present in permanently shaded craters (Watson, 1961) would provide important evidence relating to the degassing history of the moon.

or intrusive ring dike), and the Orientale Region (multi-ringed basin structure and associated rock units). This lunar sample does not include all the types of geologic features present on the moon, but the sites taken together represent a vast array of features associated with the major lunar mare and highland units and with large craters of possibly different origins. The sample also provides a nearly complete range of the different terrain conditions of slope and surface roughness present on the moon, and is useful for evaluating the range of mobility problems likely to be encountered during foot and vehicular traversing of the lunar surface.

Detailed Planning of Geologic Missions in Sites Selected for Surface Exploration

Detailed planning of geologic surface missions entails three separate but interrelated phases:

1. Compilation of photogeologic base maps, at scales commensurate with geologic evaluation and operation needs, for defining the geologic problems and for determining the most effective routes and modes of ground traversing for observing, sampling and mapping the local geology.

2. Evaluation of the minimum ground support systems and instrumentation required to meet the specified scientific objectives of the mission; and

3. Preparation of maps and instruction sheets for pre-Mission briefings and for guidance to the astronauts in fulfilling the scientific objectives of the Exploration Mission.

In the following papers on scientific mission profiles (see appendix) present levels of research permit a relatively firm evaluation of Phase I considerations. Additional research and information is required to improve evaluations based on Phase II considerations. Preparation for the third phase is just beginning and the first objective will be to develop standardized formats for most effective presentation of traverse profile and guidance information for use by the astronauts.

Data Package

Geologic maps of the moon are indispensable as a geologic tool in organizing, analysing, interpreting, and communicating, lunar information during all phases of mission planning and operation. (Figure 1)

Geologic maps with designated traverse paths and locality notations will guide the astronauts to the critical geologic features or deposits for observations and sampling. The maps will permit precise location of additional collecting and observational points deemed important by the astronauts and, through use of a coordinate grid system will permit direct communication of this information to earth.

Based on a preliminary evaluation of scientific objectives and engineering constraints of Early Apollo Missions, the U. S. Geological Survey has proposed a set of 8 x 10 1/2 inch map sheets at different scales for inclusion in the onboard Data Package. (Figure 2). Comparable map packages, custom designed to satisfy differing scientific objectives and lunar localities, should be prepared for each succeeding manned mission.

PRE-MISSION	DURING MISSION	POST-MISSION
1. Compilation at various scales for definition of geologic problems and for planning scientific ground missions. 2. Compilation of selected landing and traverse areas at large scale for pre-mission briefing of astronauts.	1. For locating LEM in relation to selenographic coordinate system and geologic features observed in flight and on ground. 2. For guidance to astronaut during ground traverses and to permit precise location of sampling and observational points along traverses. 3. Base maps in Mission Control and ADF to facilitate real time plotting of location and observations of astronaut.	1. Compilation and interpretation of ground observations and samples. 2. Extrapolation of the obtained ground information to other parts of the moon as a basis for re-evaluation of lunar geology and planning for subsequent missions.

Figure 1 - Use of geologic maps in Manned Exploration Missions

1. 1:100,000 map of region including selected landing ellipse A
2. 1:25,000 map of area covering most of the landing ellipse A (99% ellipse)
3. 25 1:5,000 maps of area covering the landing ellipse B (90% ellipse)
4. 1 clip board with coordinate grid overlay to facilitate handling and marking of maps under field conditions.

Figure 2 - U. S. Geological Survey recommendation of geologic map scales and coverage for onboard Data Packages of Early Apollo Missions. Size of map sheets and clip board 8 x 10 1/2".

SUMMARY EVALUATION OF SCIENTIFIC MISSION PROFILES PREPARED FOR SELECTED LUNAR AREAS

Mission profile evaluation of the candidate geologic sites in terms of the proposed Apollo Applications (AAP) and Advanced Systems (AS) types of ground missions are presented in the appendix. The engineering constraints, surface support systems, and instrument packages, considered in deriving these scientific mission profiles are summarized in Figure 3.

Analysis of the results support the following general conclusions:

1. Important geologic objectives can be achieved by the proposed types of missions, both of which have sufficient flexibility in equipment and mobility for utility in areas of differing terrain and geology.

2. The AAP type of mission is particularly suitable for detailed studies in areas that include major geologic contacts between mare and upland, and for mapping of the internal structures of large, flat-floored craters.

3. The AS type of mission has sufficient ground capability and instrumentation for broad regional studies required to satisfy major questions relating to lunar composition, structure, and history.

Type of Mission	Support Shelter	Stay Time	Mode of Ground Travel	No. of Ground Excursions	Geologic Instruments	Data Package	Sample Return Capability	Geologic Objectives
Early Apollo	L. M.	1 - 2 days	Foot	2 - three hour excursions	Geologic hand tools & camera staff	1:100, 000, 1:25, 000 & 1:5, 000 scale geologic maps to assist in location and traverse planning	80#	To determine the nature and origin of at least the upper 1 meter of mare material, the genesis and rock types associated with differing mare craters; and to return the greatest numbers and widest variety of samples of lunar material as possible.
AAP	LM/ Shelter with field laboratory	up to 14 days	LSSM with 8 km. operational capacity	1 - six hour excursion per day	Geologic hand tools & Lunar Surveying Staff; seismic, magnetic & gravity experiments on LSSM; petrographic microscope, X-Ray Fluorescence & X-Ray diffractometer in LM/Shelter	1:100, 000, 1:25, 000 & 1:5, 000 scale geologic maps of general area and of sites along traverses of particular geologic interest	80-250#	To obtain detailed information regarding the major types of terrain on lunar surface including mare, highlands and major craters, to test the geologic interpretations based on Orbiter data and to obtain detailed data on rock composition, surface weathering features and structure.
Advanced Systems	L.M., & small lunar base with field laboratory when required for specific missions	at least 14 days and up to 90 days	"MOBEX" with at least a 200-400 km. operating capacity	one continuous-path traverse, or a series of traverses radially from small lunar base	essentially same as in AAP type missions	1:500, 000 & 1:100, 000 scale maps covering the area traversed and 1:25, 000 & 1:5, 000 scale maps for selected areas to be examined in more detail along the traverse	at least 250#	To provide a broad regionally integrated picture of the surface geology and crustal structure of the moon. The data obtained from these traverses are essential for full interpretation of data obtained from remote sensors carried on Lunar Orbiters or sensors placed on the surface by hard- and soft-landers, and also to tie together local detailed studies made during AAP surface missions.

Figure 3 - Summary of proposed post-Early Apollo scientific type missions as compared with Early Apollo Type missions.

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National Aeronautics and Space Administration, 1965, NASA 1965 summer conference on lunar exploration and science: NASA spec. pub. 88, 421 p.

Space Science Board, 1965, Space Research, directions for the future, pt. 1: Washington Natl. Acad. Sciences - Natl. Research Council, 142 p.

Watson, K., 1961, Behavior of volatiles on the lunar surface: Jour. Geophysical Research, v. 66, no. 9, p. 3033-3045.

APPENDIX

Science Mission Profiles Prepared for the:

1. Copernicus Quadrangle
2. Aristarchus Plateau
3. Harbinger Mountains
4. North Pole Region
5. Flamsteed Region
6. Alphonsus Region
7. Orientale Region

Location of these regions in shown in Figure 4.

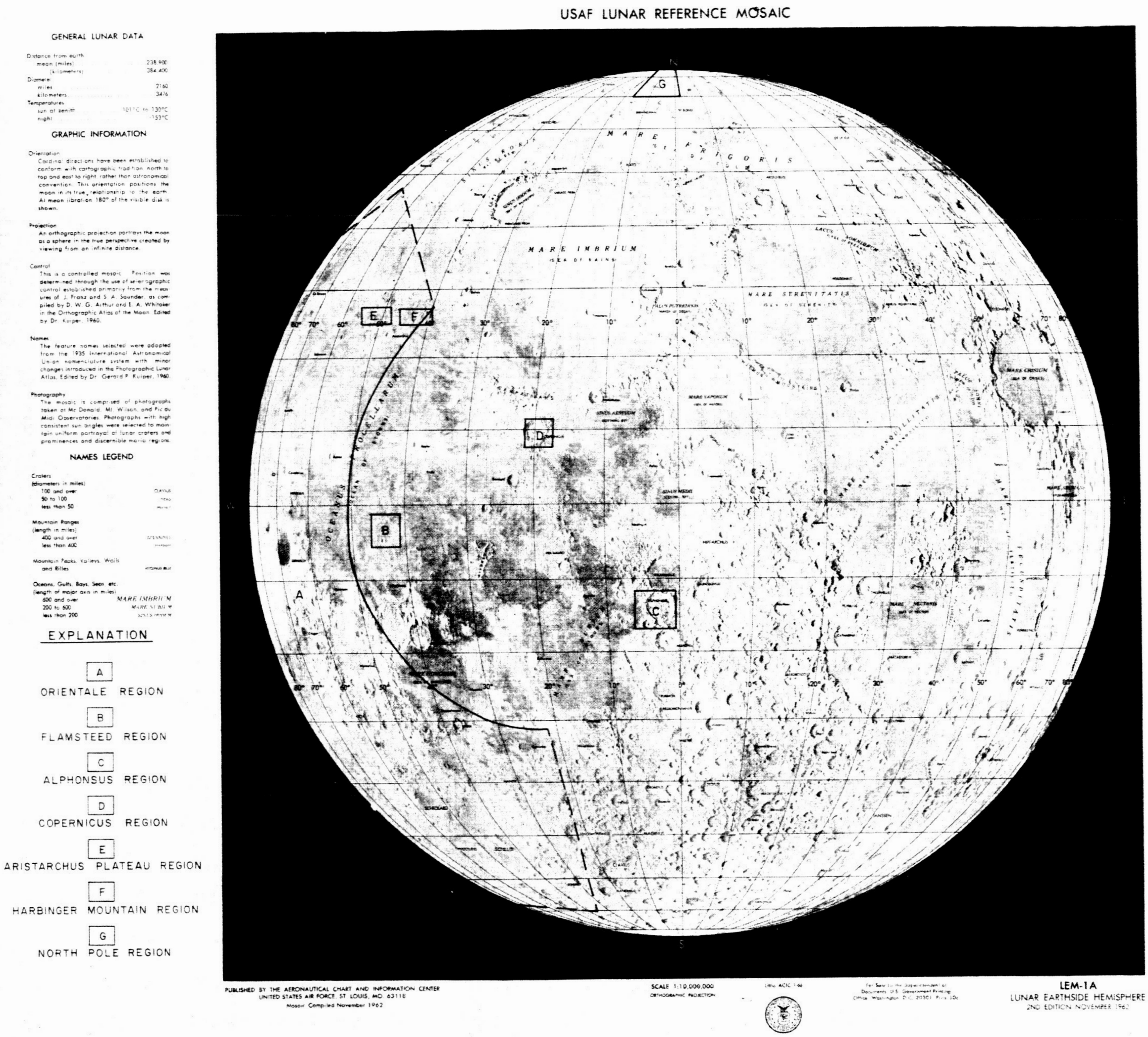

Figure 4. Index map of mean showing locations at the following regions.

SCIENTIFIC MISSION PROFILES IN THE COPERNICUS QUADRANGLE

by Newell J. Trask
U.S. Geological Survey

SCIENTIFIC MISSION PROFILES IN THE COPERNICUS QUADRANGLE

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Early Apollo Missions

One early Apollo site in the Copernicus Quadrangle has been selected for study within the ellipse II-11-2. This is within Orbiter site II-P-11, one of eight high priority sites chosen for additional detailed study by NASA. Site II-P-11 lies at the southern border of the Copernicus Quadrangle (LAC 58) directly south of the crater Copernicus and extends to the south into the Riphaeus Mountains Quadrangle (LAC 76).

General geology: The event which formed the crater Copernicus, 300 km north of the site, is responsible for the gross topography and geology of the site. Loops, lines and clusters of shallow craters and gouges are interpreted as secondary impact craters formed by material ejected from the primary crater. In places, shallow secondaries from Copernicus completely cover the surface and have produced a gently undulating plain. The Copernicus secondaries are highly eroded. On the basis of comparisons with fresh features of the same size, it is estimated that the rim heights relative to the floors have been reduced by more than 10 m. The secondary impact craters are therefore relatively early Copernican in age and are assigned provisionally to the C2 epoch. Younger, fresher craters within the ellipse are superposed on the Copernican secondaries. The youngest craters are assigned to the C8 epoch and the lower numbers indicate relatively older craters. No obvious volcanic features are present within the ellipse and it is assumed that all subdued craters are eroded impact craters. Hopefully, this hypothesis can be checked by ground investigation.

Two extensive plains units are mapped within the ellipse. The older of these (unit CEp) has very few Copernicus secondaries on it and is smoother and more level than the younger unit (Cp) which has a heavy concentration of Copernicus secondaries and is gently undulating. There are no obvious differences between the two units except those of topography. The depth of the upper fragmental layer appears to be the same on both, approximately 5 m. South of the ellipse, unit Cp has on it a fresh crater surrounded by ejected blocks that have made shallow craters and indicate a soil-like layer with substantial dynamic bearing strength (Moore, 1967). There is no reason to suppose that the properties of unit CEp are significantly different from those of unit Cp.

Details of selected site: Landing site No. 1 is placed on unit CEp close to a small C8 crater, (fig. 1). It is felt that the most significant scientific information can be obtained from the youngest, freshest features. Shock phases, for example, will be less apt to

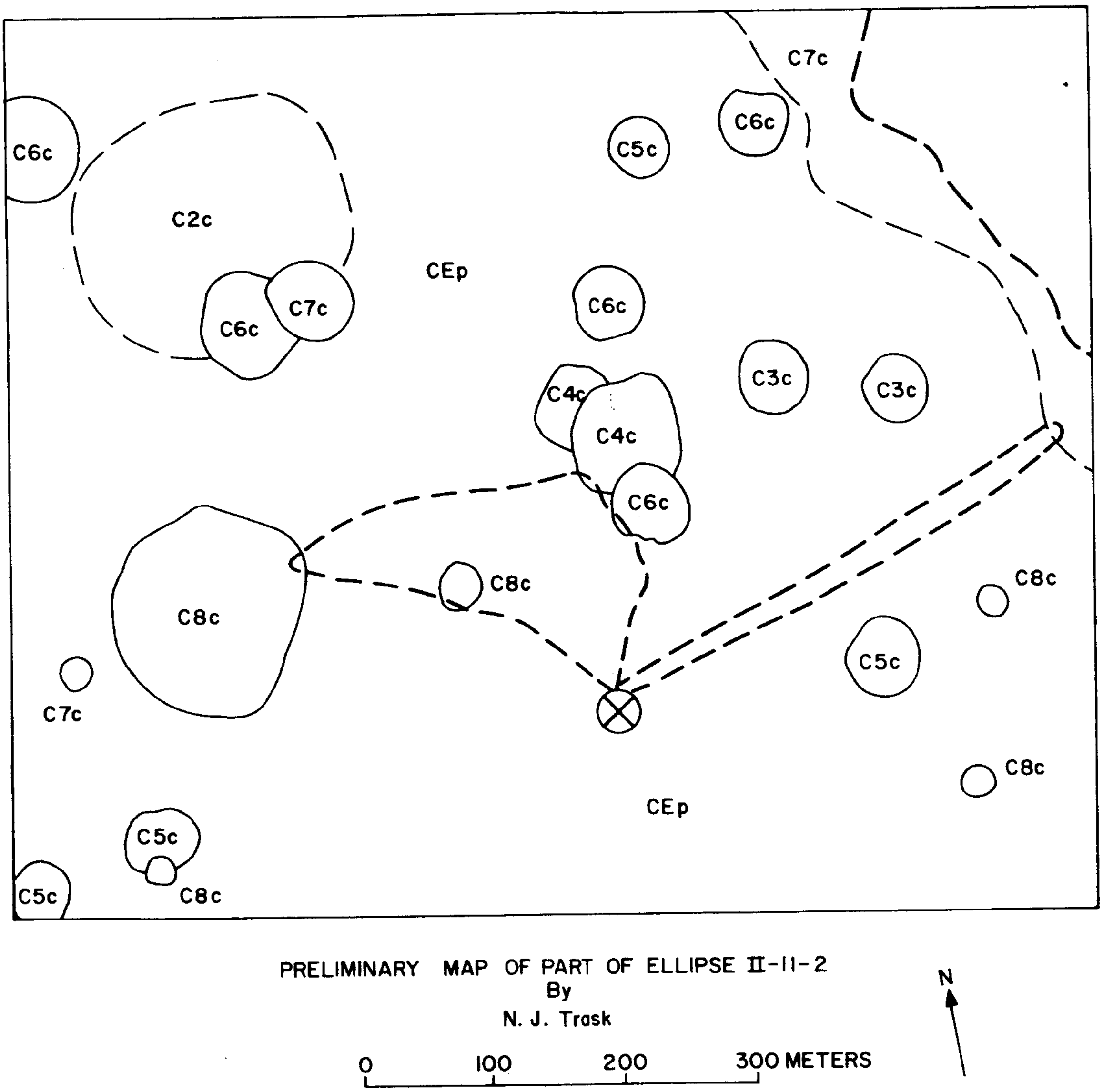


Figure 1. Early Apollo Mission in the Copernicus Region.

Explanation for Figure 1

C8c - freshest, youngest craters, bright halos, probably surrounded by sub-resolution blocks and fresh fine-grained debris - constitute a landing hazard but are objects of high scientific priority

C7c, C6c - moderately fresh craters, moderately bright halos on larger craters, probably surrounded by angular to subrounded blocks--blocks up to 6m diameter on large crater in north-east part of area--constitute a landing hazard, should be included in traverses if possible

C5c, C4c - subdued craters, no bright halos, probably have a ring of rounded, partly buried blocks close to the rim crest - less of a landing hazared than C8c - C6c, fragments probably highly altered by exposure to the space environment

C3c, C2c - highly subdued craters, no bright halos, probably only a few rounded and buried blocks on the rims - not a landing hazard, may be difficult to identify and map on the ground

CEp - plains material, gently undulating to level surface with scattered large subdued craters, gradational to terrain with abundant subdued craters (probably secondaries of Copernicus) outside the map area - fine-grained debris, generally less than 1 mm in diameter with scattered sub-resolution blocks

Explanation for Figure 1 (cont'd)

Only craters believed to have penetrated the cohesive substrate have been mapped; unmapped craters have probably only rechurned a surface layer of fragmental debris.

Outline of major block field - blocks up to 6 m diameter

The time-stratigraphic units Cl through C8 are informal and have not been adopted for use in other area.

have reverted to other forms so there is greater likelihood of finding clear evidence for or against impact (NAS question 5*). Crystalline phases in general should be more abundant in the freshest features (NAS question 4). The traverse from the landing site to the C8 crater passes many smaller craters the details of which are difficult to see on the Orbiter photographs. These should be sampled and photographed by the astronaut but the greatest emphasis should be placed on the 28 meter C8 crater which has quarried material from a depth of 7 m or below the base of the upper fragmental layer. The flat floor of the crater indicates that the lower cohesive substrate may be exposed within the crater. The astronaut should attempt to classify the smaller craters on the basis of comparison with photographs of various crater types in the data package.

A second traverse extends from the landing site to the northeast (fig. 1), and comes close to the outer margins of the rim material of a 150 m C7 crater. Since the ejecta probably extends farther from the rim than the map shows, there is good likelihood that relatively fresh material quarried from as deep as 30 m can be sampled. Comparison of the exposure age of this material with that of the C8 crater will be of interest (NAS question 14). Secondary impact craters around the C7 crater may be visible and may be partly filled with the ejecta that formed them (NAS question 7). As with the first traverse, there is a variety of smaller craters to be sampled along the second traverse.

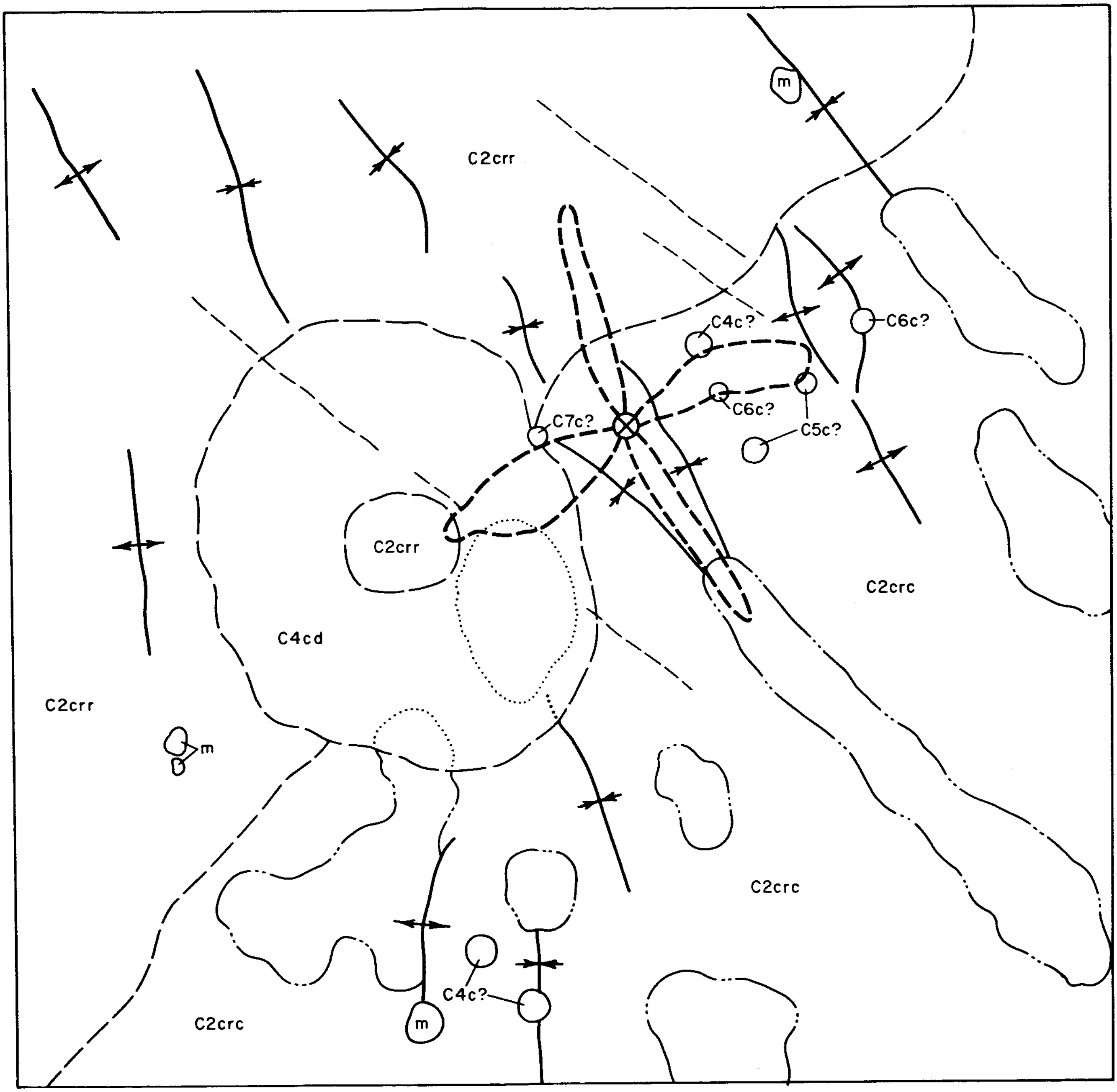
*For listing of NASA Basic Science Questions see page 39.

Summary: NAS questions 4, 5, 7, 8, 9, 13, 14, and 15 will receive some illumination from the data of these short traverses.

AAP Mission

The AAP mission is designed to investigate an area approximately 8 km in diameter centered at 18°W and 7°N. The rim material of the crater Copernicus and the crater Copernicus H are the chief features of interest.

General geology: The rim material of the crater Copernicus is interpreted as ballistically deposited ejecta in a blanket which surrounds the crater. Some of the radial texture of hills and ridges in the rim material may be caused by a "base surge" of rapidly moving gas and particulate matter close to the lunar surface. The inner facies of the rim material is rough and hummocky; most of the ballistically deposited material may be located here. A middle facies consists almost wholly of radial ridges; this is probably the result of a combination of ballistically deposited ejecta and scouring by the base surge. The outer facies consists of discontinuous ridges interspersed with secondary impact craters; comparison of the outer facies with the ejecta around large nuclear explosion craters suggests that the ground in the outer facies is first eroded and scoured by the base surge and then cratered by the impact of objects moving on higher trajectories (Masursky, personal communication). Contacts between the three facies are gradational. The landing site for the mission is placed on the contact between the middle and outer facies.



PRELIMINARY GEOLOGIC COMPILATION AND MISSION PLANNING
BY
N.J. TRASK

0 5 10km

Figure 2. Geologic Mission Traverses at the Copernicus H Region.

ABBREVIATED EXPLANATION FOR TRAVERSE MAP - NEAR COPERNICUS H

(Units listed in order of approximate relative age)

C7c, C6c - crater materials, materials of fresh craters with bright halos, halos on C7 craters brighter than those on C6 craters - materials of fresh young impact craters.

C5c, C4c - crater materials, materials of sharp craters with rim materials the same albedo as the surroundings, C4 craters slightly more subdued than C5 craters of comparable size - materials of small impact craters.

C4cd - dark halo crater material, smooth appearing material on rim of Copermicus H, normal albedo 0.98 to 0.108 - volcanic ash or sublimate of dark material, possible carbon radial.

C2crr - crater rim material, rim material of Copernicus with alternating ridges and troughs radial to the crater, normal albedo 0.109 to 0.114 - ballistically deposited ejecta partly modified by base surge.

C2crc - Cratered crater rim material, material on outer rim of Copernicus forms discontinuous ridges interspersed with shallow gouges and craters - mixture of ejecta from Copernicus and from secondary impact crater, modified by base surge.

b - mount, pile of ejecta or discrete block with corners removed by erosion.

ridge formed by ejecta and base surge

trough formed by base surge

structural lineament

outline of secondary impact crater

⊗ Advanced Apollo Program

Copernicus H is one of the best known dark-halo craters on the Moon. The albedo of the rim material is between .098 and .108 (Pohn and Wildey, 1966). This is markedly lower than the rim material of Copernicus but not especially low for the Moon as a whole. The interior of the crater has a high albedo and the crater is the location of a strong anomaly on the eclipse data of Shorthill and Saari (1965). It is thus a relatively young feature apparently of internal origin. Orbiter and Surveyor photographs have shown clearly that material ejected by impact from the cohesive substrate is initially bright and darkens with time. If Copernicus H were an impact crater, its rim material should, if anything, be brighter than the rim material of Copernicus on which it is superposed. Since the rim material is darker, it is assumed to have been brought up from depth and to have a peculiar composition so that it is either intrinsically very dark or has become dark by exposure to the space environment. Whether this material is volcanic in the sense of having once been a molten silicate or is some type of sublimate deposited in the solid state or from escaping gasses is a key question for lunar geology that can be answered by this mission.

Details of mission: Four traverse routes are planned from the landing site, approximately in each cardinal direction (fig. 2). One traverse on each route will describe and photograph the geology and collect samples; one will do active seismometry and one will do gravity and magnetics. Two days are open for contingencies.

Determination of the composition of the rim material of Copernicus H is one of the prime objectives of the mission. If the rim materials are volcanic they should be amenable to conventional petrographic methods unless they have changed completely to glass. However, provision should be made both in the equipment carried (such as a gas chromatograph) and in the astronaut's preparation for the possibility that unusual materials such as carbon, carbon compounds, other volatiles, or even organic or proto-organic material may be present. Schmitt (1967) suggested that the impact that formed Copernicus probably opened up a fracture to volatile materials trapped at depth on the Moon and that these then worked their way upward and formed Copernicus H at the surface. The crater has probably been shocked sufficiently by impact so that carbon, if present, would be partially converted to diamonds (Hanneman and others, 1967). Both cubic and hexagonal diamonds would be present and these can be distinguished with the X-ray diffractometer. Whatever the composition of Copernicus may be, its determination will shed great light on NAS questions 1, 4, 8, 9, and 12.

The composition of the rim material of Copernicus may be quite heterogeneous. The crater was excavated in mare material and the Fra Mauro Formation. The latter is itself probably very heterogeneous since it is interpreted as the ejecta produced by an impact that formed the Imbrium basin. The freshest samples should be present around the youngest small craters 10 or more meters across. Such craters cannot be identified with present photography. Greatest emphasis should be placed on collecting as large a variety of samples as possible (NAS questions 1, 4, and 10) rather than on detailed description and sampling of small craters. The effect of the base surge may be visible in the textures and topography of the rim material (NAS questions 5, 7) but may have been destroyed at the scale of ground observations by subsequent erosion.

The active seismic experiment in 4 directions should give values for the thickness and rate of change of thickness of the Copernicus rim material. The effective depth from which seismic data can be obtained has been given as 3 km. The thickness of the Copernicus rim material at this location is much less than this, so additional information on the vertical structure of the mare material which probably underlies the rim material would be obtained. A tripartite passive seismic array placed on this mission will yield more data than the single station of early missions (NAS question 1).

Gravity and magnetics may give an indication of the depth of the feeder pipe for Copernicus H in addition to the gross structure of the Moon at this location (NAS question 3). Placement of magnetotelluric array could also be accomplished. A heat flow measurement in the vicinity of Copernicus H should be attempted if at all feasible (NAS question 12).

Advanced Systems Mission

The Advanced Systems mission focuses on the floor of Copernicus, a feature that has come to be regarded as a "classic" impact crater on the Moon (Shoemaker, 1962). Many of the features on the floor of the crater, though not incompatible with an impact origin, are puzzling and have stirred considerable controversy; they also occur in many other large craters so the results of this mission would have wide applicability.

General geology: The crater Copernicus is 90 km in diameter, has bright rays and is a strong thermal anomaly in the eclipse measurements. The loop pattern of many of the satellitic craters surrounding the rim of ejecta--strongly evident on Orbiter as well as earth-based photographs--is strong evidence that the crater formed by impact (Shoemaker, 1962). The crater has evidently undergone modification since its formation as shown by the subdued nature of the rim, level smooth patches within the rim material, the dark-halo craters on its wall and rim, and the unusually dark sector in the rim material on the south side. Whether these modifications are the result of normal lunar processes of erosion and degassing or were in some way triggered by the impact is a key problem of lunar geology on which some light can be shed by this mission.

The floor material of Copernicus is divided into two facies, the hummocky and the smooth, with a relatively sharp contact between them.

The smooth material appears to have filled in and surrounded the hummocks of the hummocky facies; the smooth facies has been interpreted as a later volcanic deposit or as a smoothed and eroded portion of the hummocky facies. The hummocky facies has been interpreted as the top of a shock-crushed breccia lens on which sharp corners and peaks had been rounded by erosion. Orbiter IV photographs show that the hummocky terrain has been extensively smoothed and the hummocks have a wide range of sizes. Most of the hummocky facies do not look volcanic; the facies is crossed by many strong lineaments which are parallel to the walls of the crater suggesting that pre-existing lines of weakness controlled the breakup of the target material (Shoemaker, 1962). Schmitt, Trask and Shoemaker (1967) suggested that the smooth facies occurred where shocked and brecciated Fra Mauro Formation occurred at the surface and was more easily eroded than the supposed volcanic materials of the mare material which formed the hummocky facies. Sampling of the surface materials, seismic profiles, gravity and magnetics should provide a choice between these possibilities.

The central peak of Copernicus, like all central peaks in large craters, has had no really satisfactory explanation. Masursky (personal communication) has suggested that central peaks form by the rebound of a plug of shock-crushed breccia immediately after the crater-forming impact; the plug would be similar to the central uplift at the Flynn

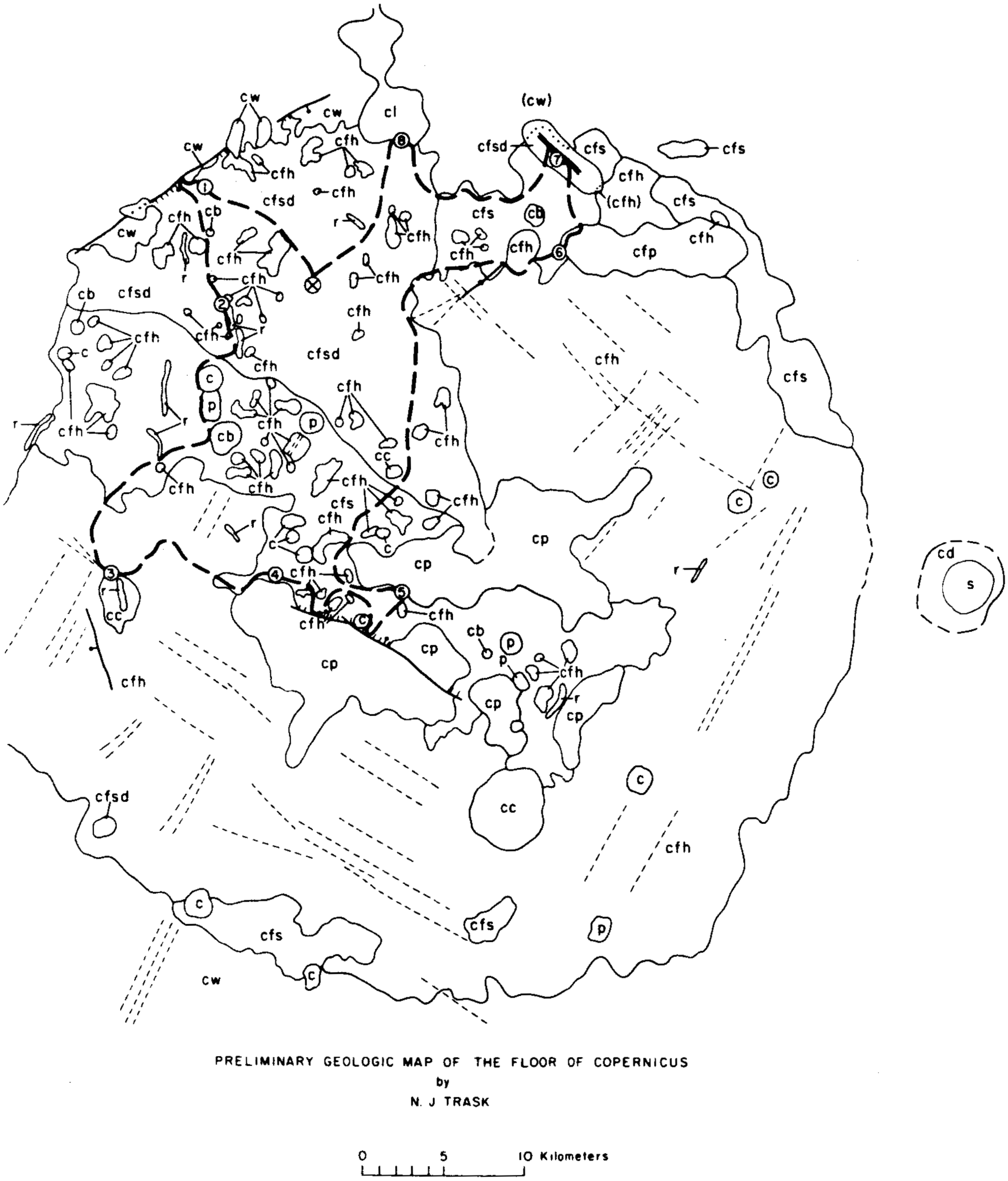


Figure 3. Geologic Mission Traverses in the Crater Copernicus.

ABBREVIATED EXPLANATION FOR TRAVERSE MAP - FLOOR OF COPERNICUS

(All units are Copernican, listed in order of approximate relative age)

cb - crater material, material of craters with bright ejecta - material of small impact craters.

cl - lobe material, material that has flowed down north wall of Copernicus and encroached on floor - debris flow of bedrock fragments.

s - slope material, material with high albedo on the wall of Copernicus A - talus and exposed bedrock.

r - rille material

cfsd - dark, smooth floor material, normal albedo 0.14-0.15 a few craters of darker material, level except for a few low mounds, slightly less cratered than cfs - volcanic flows, probably mafic to ultramafic, may be debris flows with carbon and polymerized hydrocarbons.

cd - material of dark halo crater, normal albedo 0.14-0.15, appears smooth - volcanic ash or sublimate of carbon or carbon compounds.

cfs - smooth floor material, normal albedo 0.15-0.16, level except for a few low mounds, slightly more cratered than cfsd - like csfd but older and mixed with brighter material of hummocky floor material.

c - crater material, material of craters with ejecta nearly the same albedo as the surroundings - material of small impact craters.

p - rimless pit, relatively deep crater with no rim - collapse feature, new material has probably not been brought to the surface by the vent.

cfp - pitted floor material, level except for a cluster of 20 craters 100 to 500 meters in diameter, crater rims are sharp, nature of rim material cannot be determined - maar field, pyroclastics between craters.

cc - material of cratered cone, broad mound, convex upward with summit crater or rimless depression - shield volcano or block of megabreccia bowl that has degassed because of disequilibrium after impact.

cfh - hummocky floor material, normal albedo 0.15-0.16, rounded hummocks 200 to 2000 meters in diameter and 50 to 150 meters high, hummocks roughly elliptical, many occur in lines parallel to adjacent lineaments - top of megabreccia bowl formed by impact.

cp - crater peak material, material of mountains on the floor of Copernicus, individual peaks 1 to 5 km in diameter, 500 to 1000 meters high smooth appearing, 4 peaks have summit craters, normal albedo 0.17 -

rebounded plug of megabreccia bowl, may have undergone degassing.

cw - wall material, hummocky to smooth material on walls of Copernicus - shocked and brecciated bedrock, highly slumped.

Creek, Tennessee structure (Roddy, 1966) which has brought up material over a stratigraphic interval of several thousand feet. A common alternative suggestion is that the central peaks are volcanic plugs and domes formed a considerable time after the impact. Carr (1964) showed that the disruption of the thermal gradient around a large impact crater might be sufficient to initiate melting and cause later volcanism. Distinction between these proposed theories should be possible by ground inspection even from a considerable distance.

Extensive downslope movement of material is evident on Orbiter photographs (II and IV) of the walls of Copernicus; in places large aprons of debris appear to have encroached on the floor. These debris flows are of interest in their own right and also as a means of access to a variety of rock types that are probably exposed on the walls of the crater.

There are a number of interesting albedo variations on the floor and walls of the crater. A pie-shaped area with lower than average albedo is present on the smooth floor material in the northwest corner and dark spots and patches are present on the south and southeast walls. These dark areas may reflect differences in composition or exposure ages and can be investigated by systematic sampling along the proposed traverse.

Details of mission: The landing site for the mission is in the middle of the dark smooth floor material (point X, figs. 3, 4) (NAS

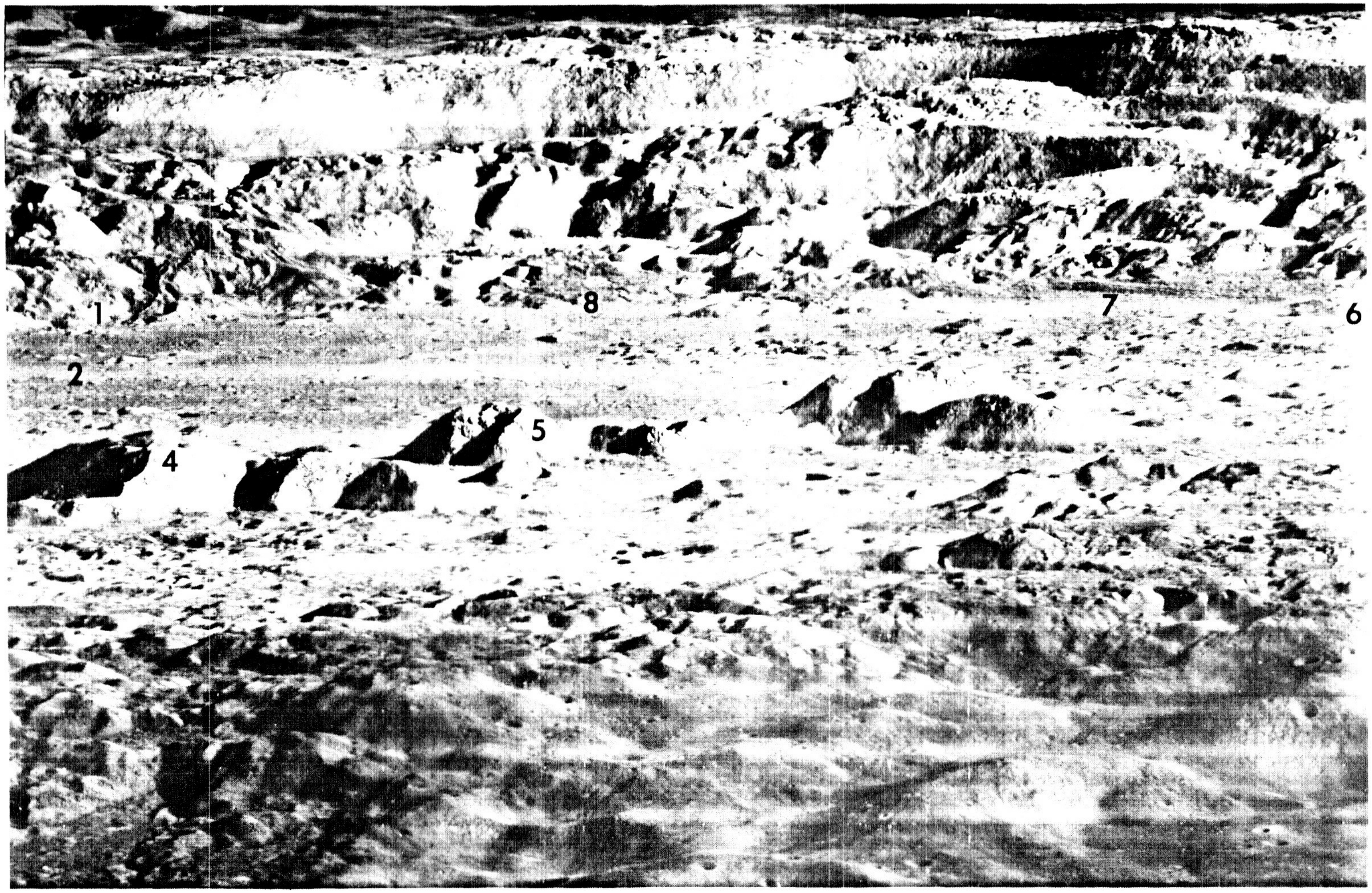


Figure 4 - Oblique view of the crater Copernicus with locations discussed in the text.

questions 4, 8) and a traverse of approximately 200 kms is planned around the periphery of the smooth floor material. The traverse will sample examples of all types of features present on the floor; the results can be extrapolated to less trafficable parts of the floor by remote sensing and unmanned roving vehicles. Continuous seismic profiling will be made on this traverse if early results are promising. It should be recognized, however, that the chaotic nature of any shock-crushed breccia which may be present in the near subsurface may make seismic interpretation very difficult if not impossible as it is in terrestrial areas such as the central Powder River Basin of Wyoming where chaotic breccias have been produced at the surface by the recent burning of coal beds. Gravity and magnetics should give indications of the depth of the breccia bowl (NAS question 1). The crater is generally regarded as having been made by a comet (Shoemaker, 1962; Carr, 1964) so evidence of an iron meteorite at depth is unlikely.

The traverse proceeds to the wall material at point 1 (figs. 3, 4). The straightness of the contact between the wall material and the floor at this point suggests a fault (fig. 3); the smooth floor material appears to post date and partly cover the fault. Determination of the movement sense on this feature would be of considerable interest. If the floor has moved up relative to the wall, it would suggest that Copernicus is in the first stages of isostatic rebound (Masursky, 1964); if the floor has moved down relative to the wall, the fault may be one of the series of concentric slump features evident elsewhere on the wall which have resulted in general centripetal movement of material since formation of the crater. In either case NAS questions 5 and 6 are relevant.

Several small rilles are present in the smooth floor material to the south of the fault (2, figs. 3, 4). Bedrock typical of the smooth floor material may be exposed in the walls. Details of the rilles are not well shown on available photography but they appear to be quite sinuous and thus the problem of sinuous rilles may be attached (NAS questions 5, 7). The average composition of the rims should be compared with that of the smooth floor material away from the rilles in case they may be the source of the smooth material.

The contact between the smooth and hummocky facies is crossed and the traverse proceeds to a larger and sharper-appearing rille on the hill at point 3 (fig. 3). The rille heads in a rimless crater at the summit of the hill. The entire feature is one of two very volcanic appearing prominences on the floor of the crater and deserves detailed study (NAS questions 4, 8). If the hill is not volcanic, it may be a block of the megabreccia bowl that has undergone violent degassing and possibly subsequent collapse due to disequilibrium in the block immediately after impact. The capability of analyzing for carbon compounds and/or organic or proto-organic materials should be available for these and all other features of possible internal origin.

The traverse then proceeds to the western composite hill of the central peak (4, figs. 3, 4); boulders at the base of the slope can be examined and analyzed (NAS questions 1, 10). A fault has been mapped along the northern boundary of this block and may be evident on seismic, gravity or magnetic records (NAS question 6). The middle central peak is then studied (5, figs. 3, 4). The appearance of this peak has led some observers of Orbiter II photographs to suggest that it is a breached cinder cone or plug with the dark stripe on the southeast side being a lava flow. Other observers believe that the dark stripe is the outcrop of a titled resistant bed and that the peak is therefore one block of a megabreccia bowl.

The traverse then turns north and covers a large segment of the smooth floor material that includes scattered islands of the hummocky facies. In the northeast corner of the floor is cluster of sharp craters averaging 0.5 km in diameter (6, figs. 3, 4). The areal distribution of these craters indicates that they are either of internal origin or are a field of secondary impact craters. There is no nearby impact crater of the requisite size younger than Copernicus that might have been the point of origin of the secondary fragments unless it is Kepler some 500 km to the south which seems unlikely. The first alternative seems most likely and the craters are probably part of a maar field. Three contrasting types of possible volcanic features can thus be sampled in the mission: a broad shield-type volcano with summit crater (3, fig. 3); a breached cinder cone or plug (5, fig. 3); and a maar. Possible contrasts in composition are relevant to NAS question 4. As on earth, cognate inclusions and/or xenoliths from depth may be present around some of these forms but not around others.

A relatively short graben is present at 7 (figs. 3, 4). The area surrounding it is slightly darker than typical floor material and the graben may be another source of the smooth floor material. Bedrock may be in place on the walls.

The traverse then proceeds to the north wall of the crater where a large well-defined flow is evident on both Orbiter II and IV photographs (8, figs. 3, 4). The floor probably consists of debris from the walls of the crater but could conceivably be volcanic. Shoemaker (personal communication) has suggested that volatiles, momentarily released by the impact, lubricated the downslope movement of debris from the walls. The composition of the flow will be of prime interest (NAS questions 4, 8) but it may also be possible to study the geometry and mechanism of the flow (NAS question 7).

Because Copernicus is relatively young, as large features on the Moon go, exposure ages determined for a wide variety of materials on its floors and compared with those for older materials may shed light on NAS questions 13 and 15.

NASA BASIC SCIENTIFIC QUESTIONS

1. Is the internal structure of the Moon radially symmetrical like the Earth, and if so, is it differentiated? Specifically, does it have a core, and does it have a crust?
2. What is the geometric shape of the Moon? How does the shape depart from fluid equilibrium? Is there a fundamental difference in morphology and history between the sub-Earth and averted faces of the Moon?
3. What is the present internal energy regime of the Moon? Specifically, what is the present heat flow at the lunar surface, and what are the sources of this heat? Is the Moon seismically active, and is there active volcanism? Does the Moon have an internally produced magnetic field?
4. What is the average composition of the rocks at the surface of the Moon, and how does the composition vary from place to place? Are volcanic rocks present on the surface of the Moon?
5. What are the principal processes responsible for the present relief of the lunar surface?
6. What is the present tectonic pattern on the Moon and distribution of tectonic activity?
7. What are the dominant processes of erosion, transport, and deposition of material on the lunar surface?
8. What volatile substances are present on or near the surface of the Moon or in a transitory lunar atmosphere?
9. Is there evidence for organic or proto-organic materials on or near the lunar surface? Are living organisms present beneath the surface?
10. What is the age of the Moon? What is the range of the age of stratigraphic units on the lunar surface, and what is the age of the oldest exposed material? Is a primordial surface exposed?
11. What is the history of dynamical interaction between the Earth and the Moon?
12. What is the thermal history of the Moon? What has been the distribution of tectonic and possible volcanic activity in time?
13. What has been the flux of solid objects striking the lunar surface in the past, and how has it varied with time?
14. What has been the flux of cosmic radiation and high-energy solar radiation over the history of the Moon?
15. What past magnetic fields may be recorded in the rocks at the Moon's surface?

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SCIENTIFIC MISSION PROFILES IN THE ARISTARCHUS PLATEAU AND HARBINGER MOUNTAINS

by Henry J. Moore
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Apollo Applications Program and Advanced Systems

Geologic Traverses on the Aristarchus Plateau

by

Henry J. Moore
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Introduction

A number of craters on the Aristarchus Plateau are morphologically similar to terrestrial calderas, rampart maars, and maars. In addition, a long broad sinuous rille, called Schröter's valley, transects the plateau in an east-west direction. The age of formation, their origin, and the composition of their materials are unknown.

The purpose in examining the features on the plateau is to ascertain the origin, age, and composition of materials of the features above. For an advanced Apollo Mission lasting 14 days and constrained to a circular area with 8 km radius a few selected features could be examined in detail. For example, the crater Herodotus D could be studied to see if it is a caldera and the contact between mare material and materials surrounding Herodotus D could be examined; or the west tip of Schröters valley could be studied.

Extensive and complete exploration of the Aristarchus Plateau would require at least two open traverses 200 km long and taking 14 days. One of these would start near Herodotus D and finish near the west tip of Schröter's valley. Although closed traverses could be used here, the

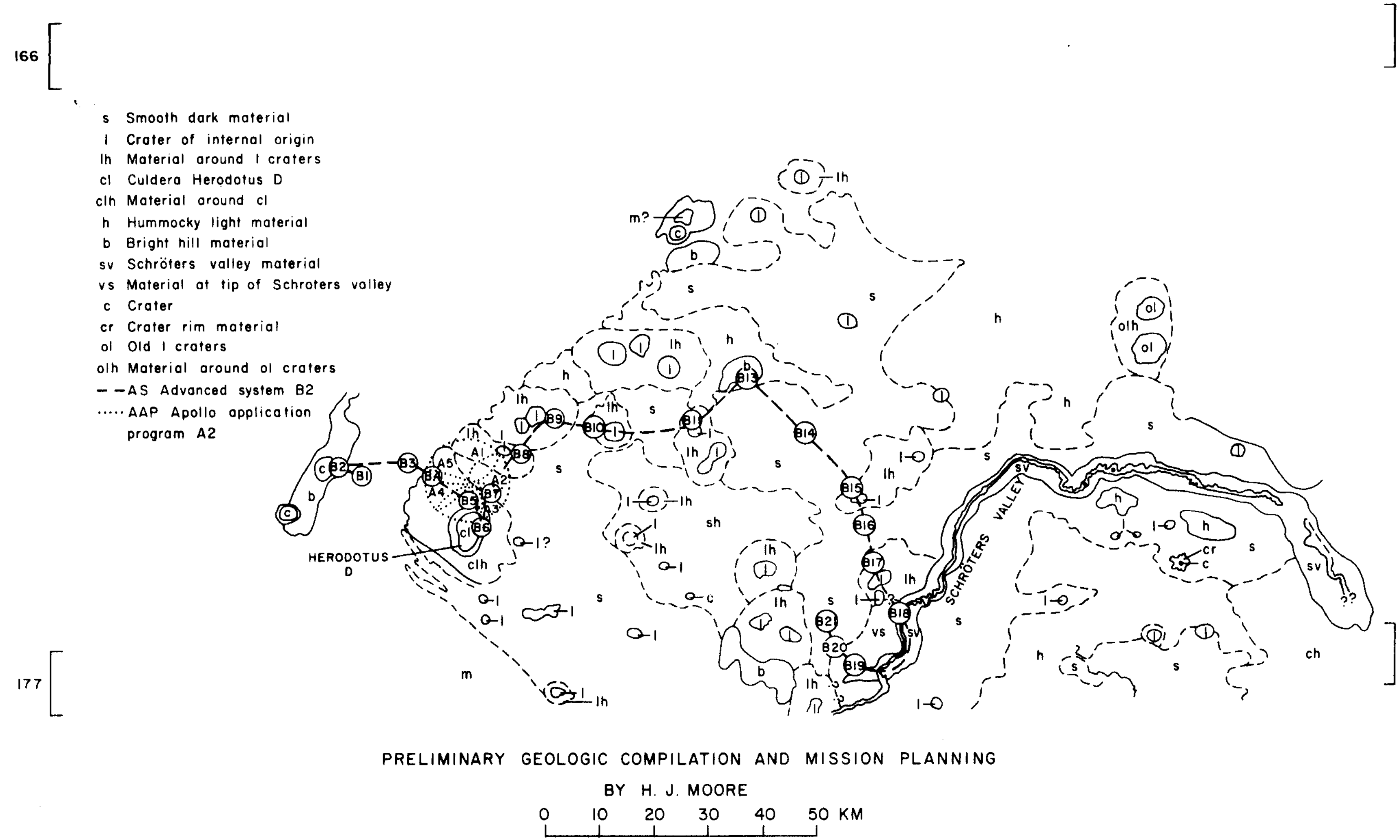

Figure 1. Geologic mission traverses for Apollo Applications Program and Advanced Systems Exploration of the Aristarchus Plateau.

large distances between the major features would require more missions than for open traverses.

Traverses

A sample traverse for each exploration program is shown in figure 2. For the Apollo Applications Program Traverse (see A in figure), the express purpose is to examine Herodotus D and a possible maar crater to the N. E. (A. 1). The traverse includes:

A. 1	Examination of crater and crater halo.
A. 2	Examination of unit s.
A. 3	Examination of rim and inside of Herodotus D (cl).
A. 4	Examination of material around Herodotus D (clh).
A. 5	Examination of mare material (m) and contact between mare material (m) and material around Herodotus D (clh).

The sample open traverse for Advanced Systems Exploration is designed to visit the largest number of varied features possible (see traverse B, figure 2). The traverse begins on the mare and ends near the tip of Schröter's valley. It includes:

B. 1	Land and study mare material (m).
B. 2	Examine bright hill material (b), contact between mare material (m) and bright hill material (b).
B. 3	Examine mare material (m) contact with Herodotus material (clh).

B. 4	Examine Herodotus material (clh).
B. 5	Examine rim of Herodotus.
B. 6	Examine floor of Herodotus.
B. 7	Study contacts clh/s and s/lh.
B. 8/B. 9	Examine craters and crater materials.
B. 10	Examine possible rampart maar crater.
B. 11	Study unit s.
B. 12	Another rampart maar?
B. 13	Study bright hill material.
B. 14	Study unit s.
B. 15	Study crater and surrounding materials.
B. 16	Unit s again.
B. 17	Another rampart maar crater?
B. 18	Examine Schröter's Valley.
B. 19	Examine scarps and materials here.
B. 20	Examine scarp here.
B. 21	Study unit s and pick up.

Recommended maps

Photograph at a scale of 1:660, 000 and annotated photograph at same scale to point out salient problems.

Recommended equipment

1. Hand lens, geology pick, sample bags.

preliminary attempt to establish a suitable traverse for geologic exploration of the Harbinger Mt. complex is shown in figure 2. The itinerary would be as follows (numbers on map correspond to numbers below):

1. Land, check out spacecraft for return flight and equipment, study mare material (ds).
2. Examine scarp and contact between units ds and mh.
3. Examine scarps and materials of ds and ms.
4. Examine contact (?) between units mh and ms.
5. Study crater (c) and unit ch. Are these volcanic (?)
6. Same as 4.

6a. Examine secondary impact craters produced by ejecta from Aristarchus.

7. Study unit b and contacts with mh.
8. Examine depression (r).
9. Study large circular depression, is it a caldera?
10. Study unit b and contacts.
11. Study unit p

10a. Examine secondary impact craters produced by ejecta from Aristarchus

12. Examine head of sinuous depression (rc), is it a volcanic basin?
13. Find out what is covering buried crater.

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9. Study large circular depression, is it a caldera?
10. Study unit b and contacts.
11. Study unit p

10a. Examine secondary impact craters produced by ejecta from Aristarchus

12. Examine head of sinuous depression (rc), is it a volcanic basin?
13. Find out what is covering buried crater.

14. Examine sinuous depression, volcanic? collapse?
15. Examine depression and crater on hill.
16. " " " " " "
17. Study tip of depression (r).
18. Recheck contact ds-mh-ds or examine floor of sinuous depression near 18.

Maps

The only maps required would be a photograph at a scale of 1:500,000 because of the reconnaisance nature of this mission. Topography and location by resection should yield sufficiently accurate locations. The traverse might be indicated on a duplicate map with a number guide to explain salient problems.

SCIENTIFIC MISSION PROFILES IN THE NORTH POLE REGION

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ADVANCED SYSTEMS GEOLOGIC TRAVERSES IN THE NORTH POLE REGION OF THE MOON

by George Ulrich
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INTRODUCTION:

Two advanced systems type of ground traverses were selected for the northern polar region after preliminary geologic compilation and evaluation of the terrain characteristics and geology of the region (Figure 1).

Important features and topics to observe are briefly noted for the stations shown along the traverses.

I. North Pole Traverse

No smooth landing sites of the Early Apollo type observed. Surface heavily pitted by 1 - 1.5 km craters.

1. Temperature regime
   Surface materials
   Surface processes

1-2. Temperature variation with Latitude
   Affects on types of surface materials
   Stratigraphy in walls of fresh craters

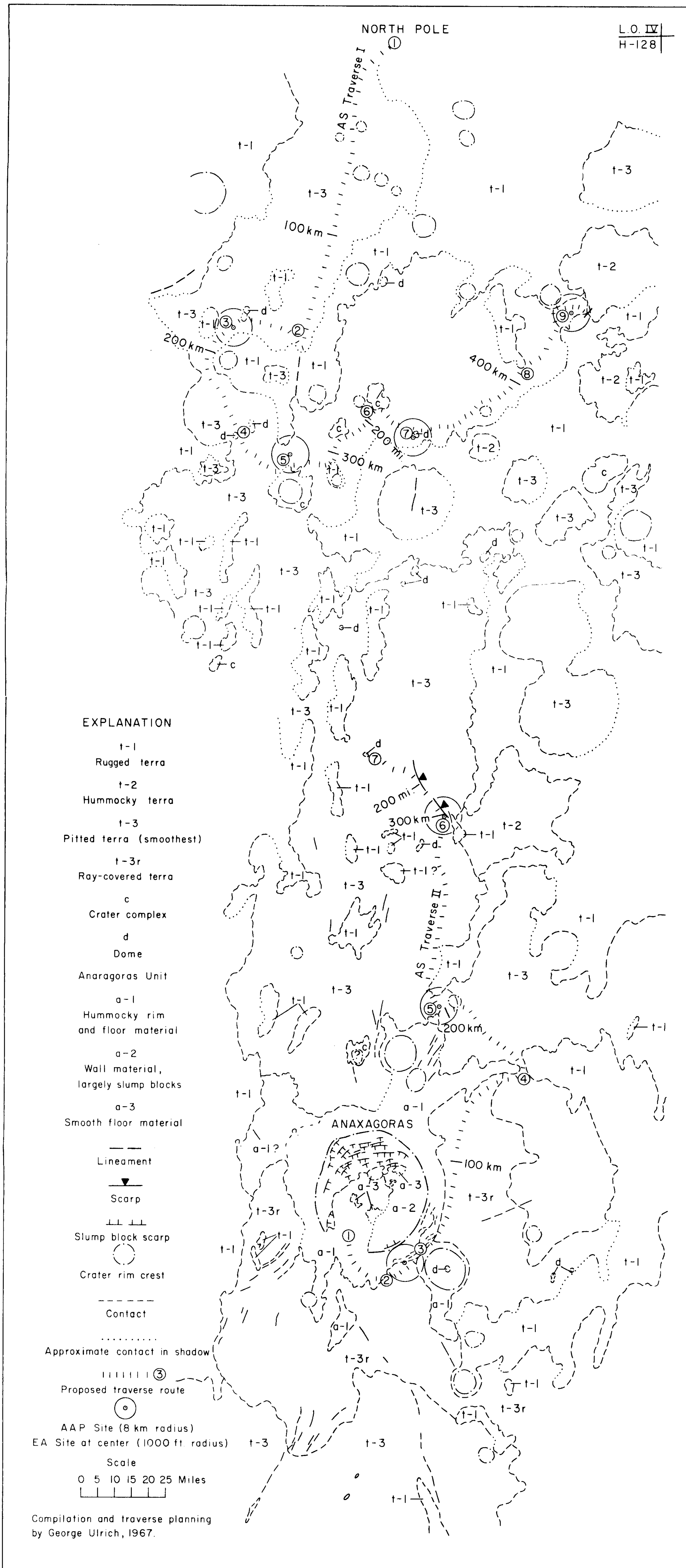

Figure I. GEOLOGIC MISSION TRAVERSES NEAR THE LUNAR NORTH POLE

2. Materials in large perennially shaded area

North-south valley--structure and stratigraphy

3. Domes on t-3

Comparison of t-1 rocks on north and south with t-3

Large (8 km), fresh, smooth-rim crater

4. Domes on t-3

5. Sharp-rimmed crater (11 km diam.), stratigraphy and structure

6. Crater cluster on t-3

Structure

7. Dome on t-3

North rim of old crater

Temperature effects in perennially shaded area

7-8. Correlation of rock types along t-1 slopes

8. Comparison of t-1 on North and South of t-3

9. Comparison with rock types and stratigraphy from 7 and 8

Nature of t-2 hummocky surface

II. Anaxagoras Traverse

Smooth terrain buried by ejecta south of Anaxagoras provides possible landing site.

1. LFV (flying vehicle) required for on-site description and sampling
   Very hummocky surface on breached south wall of Anaxagoras (a-1)
   Slump blocks on north wall (a-2)
   Compare smooth areas (a-3) in floor with a-1 and a-2
   Stratigraphy of crater wall
2. Compare a-1 surface and rocks with t-3r which appears to be buried t-3

2-7. Measure changing temperature regime

3. Concentric scarps on Anaxagoras (SE) rim
   Compare 17-km crater rim with Anaxagoras to determine if stratigraphy is similar and whether covered by Anaxagoras ejecta

3-4. Nature of t-3r/t-3 contact
   Detailed morphology and rock types of NE-trending radial ejecta

4. Comparison of a-1, t-1, and t-3 surfaces and rock types

4-5. Surface heavily pitted by craters smaller than 1 km. Determine whether secondaries from Anaxagoras

5. Comparison of a-1 to south with t-1 on north
   Stratigraphy in wall of 6-km crater to east

5-6. Assymetrical depression, 7 km long, on west side of t-1 ridge

Fresh cratered surface, 1-1.5 km diam.

6. Northwest-trending scarp; structural or volcanic

Compare t-1 with observations at 4 and 5

6-7. Trace scarp, note effects, if any, on craters

7. Dome on t-3

SCIENTIFIC MISSION PROFILES IN THE FLAMSTEED REGION

by Thor N. V. Karlstrom
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PREPARATION OF GEOLOGIC MISSIONS IN THE FLAMSTEED REGION

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Description of Site

The Flamsteed Ring structure is located in Mare Procellarum and centered about 3° south latitude and 44° west longitude near the west limb of the moon (Figure 1). Analysis of Lunar Orbiter I and III photography covering the northeast part of the Ring structure permits delineation of four major terrain units (Figure 2):

1. Discontinuous ridges (Tu), rising as much as 1,000 feet above the surrounding terrain, that make up part of the Flamsteed Ring.

2. A dark densely cratered regional mare unit (DM) that surrounds, separates, and embays the irregular shaped upland ridges.

3. A linear ledge and ridge unit (MTl) that lies along the mare-upland contact and which rises 50 - 100 feet above the mare surface; and

4. Long sinuous mare ridges (Mr) in part concentric with the upland structure, that rise as much as 100 feet above the surrounding mildly undulating mare surface.

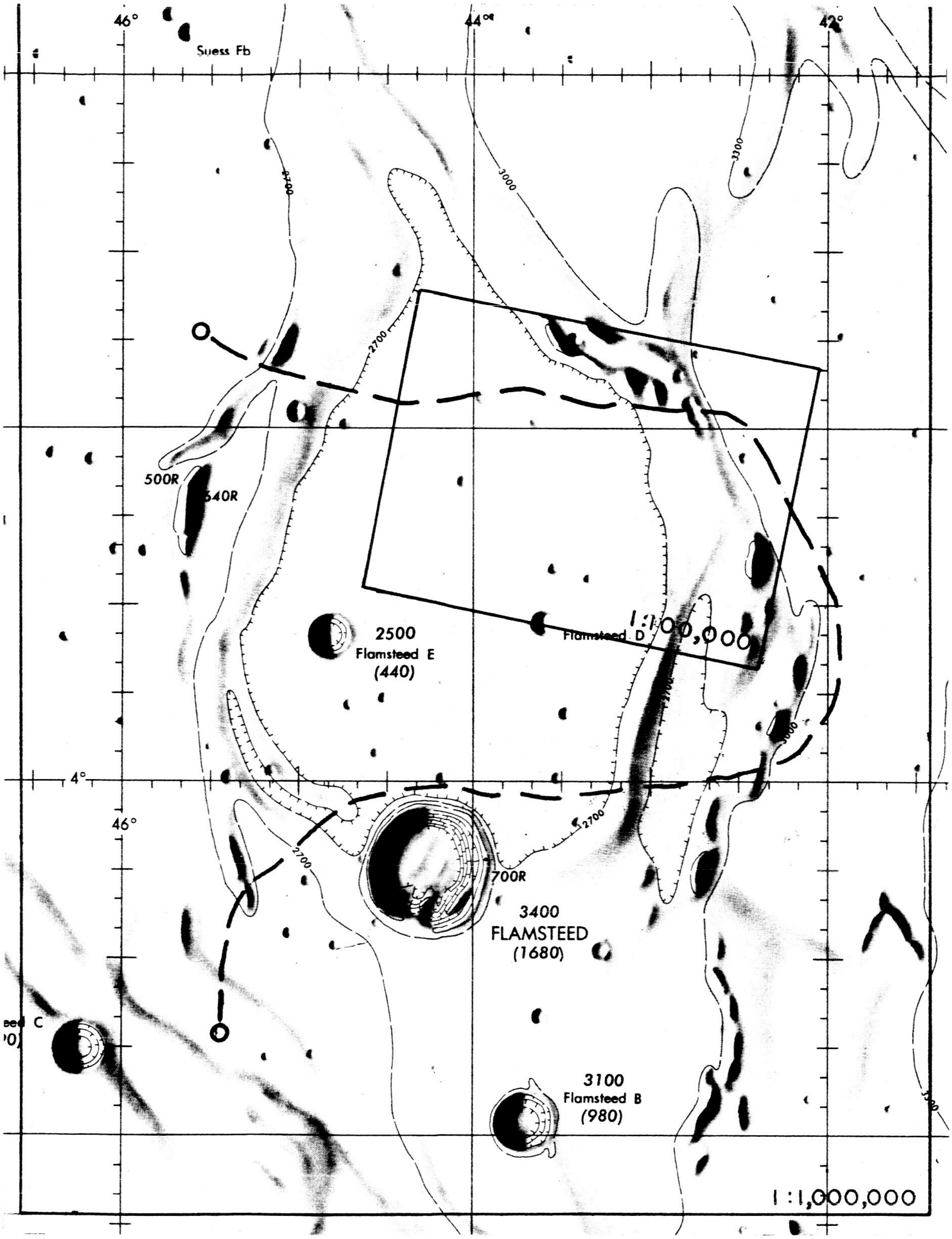

Figure 1 - The Flamsteed Ring Structure in Mare Procellarum near the west limb of the moon compiled on 1:100,000 scale LAC-75. The outlined base locates the area covered at larger scale in Figure 2. The dashed line illustrates an Advanced Systems path type of mission profile 1.

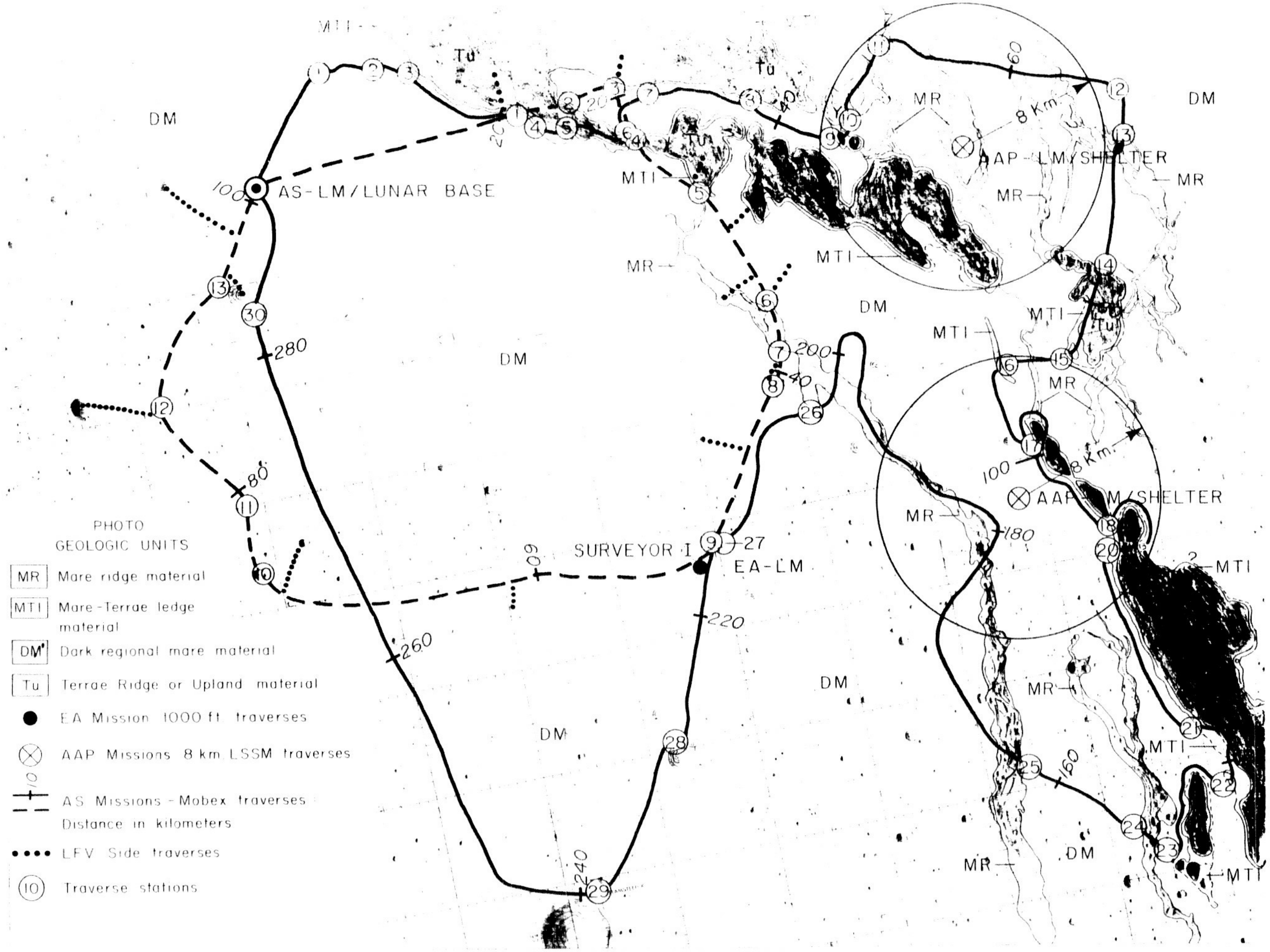

FIGURE 2. GEOLOGIC MISSION TRAVERSES IN FLAMSTEED REGION

SCALE KILOMETERS

0 5 10 15 20

Base compiled on 1:100,000 LAC chart 75A

GEOLOGIC COMPILATION
BY THOR N. V. KARLSTROM, 1966

Photogeologic Interpretation and Definition of Geologic Problems

Current interpretations of lunar geology have of necessity been largely derived from the telescopic and photographic record of lunar surface features, and from comparisons of these lunar features with terrestrial surface features of known origin. Terrestrial mapping experience indicates that topographic expression of surface deposits does not necessarily provide unique compositional or genetic interpretations, and that repeated ground observations are commonly required to eliminate bothersome alternate interpretations and to refine the technique of proper photogeologic identification of geologic rock units from their surface form and textual characteristics.

Despite these limitations, terrestrial photogeology has proven extremely valuable in geologic mapping by establishing the major geologic units for study; in defining the important geologic problems; and in locating those areas where ground observations and sampling should be concentrated. That the same advantages and limitations apply to photogeologic interpretations of lunar geology is well illustrated in the Flamsteed region where different genetic interpretations have been placed on the defined photogeologic map units shown in Figure 2.

The most generally held interpretation of the Flamsteed Ring (Tu) is that it represents the tectonically sculptured rim of an ancient crater presumably of impact origin, that was subsequently filled, largely buried, and surrounded by deposition of mare material of either lava

	Tu = old crater rim	Tu - ring dike intrusive
MTl = volcanic either mare ledge or contact dike	A 3. Formation of marginal ledge during cooling of mare fill (MTl) 2. Mare deposition (DM) 1. Crater formation (Tu)	B 3. Intrusion of MTl as contact dike penecontemporaneous with or after event 2. 2. Intrusion of Ring Dike (Tu) 1. Deposition of regional mare (DM)
MTl = colluvium	C 3. Deposition of colluvial deposits (MTl) 2. Deposition of mare (DM) 1. Crater formation (Tu)	D 3. Deposition of colluvial deposits at base of upland elapse (MTl) 2. Intrusion of ring dike (Tu) 1. Regional mare deposition (DM)

Figure 3 - Regional geologic histories of the Flamsteed Region resulting from different interpretations of photogeologic units.

or pyroclastic composition. Recently John O'Keefe and others, (1967) and Fielder (1967) present arguments in favor of the interpretation that the structure represents a ring dike intrusion that postdates mare deposition.

Unit MTl, first recognized from the analysis of Lunar Orbiter photography has been variously interpreted as (1) a colluvial deposit formed at the base of upland shapes as a result of fragmentation and down-slope movement of surface materials; (2) a dike injected along a structural contact between upland and mare; and (3) a marginal mare ledge representing original flooding levels, left suspended along depositional basin margins, by subsequent cooling and contraction of the mare fill.

Strikingly different interpretations of regional geologic history result from combining the different interpretations placed on these two photogeologic units (Figure 3).

Some geologic consequences become clear from the analysis of these four different reconstructions. Interpretation of unit MTl as a mare ledge is impossible in sequence B since formation of a marginal mare ledge requires that formation of the upland rim structure predate mare deposition. Conversely, if unit MTl is a mare ledge then sequence B, C and D may be reasonably eliminated. The proper indentification of unit MTl is thus central to the geologic interpretation of the Flamsteed region.

Additional photogeologic observations bear directly on the geologic history of the Flamsteed site:

1. Crater density is greatest on the mare surface, less on the uplands, and least on the marginal ledge feature.

2. Lineament density is greatest in the uplands, less on the marginal mare feature, and least in the mare. Analysis of lineament directions indicate that preferred lineament directions in sampled areas of the mare, upland and marginal ledge coincide with prominent lunar grid directions suggesting a common control by a fundamental fracture system present in lunar crustal rocks.

3. Many mare craters of all sizes and ranging from the sharpest rimmed craters to the most subdued in form show one or more straight sides that line up or coincide with strong lineaments in the mare as marked by depressions scarps, chains of small craters, small ridges and locally lines of boulder-like blocks. It is not entirely clear whether this modification of crater form predominantly resulted from fracturing that predated, occurred during, or postdated crater formation; and

4. The mare ledge units is a bench-like form where present at the base of upland slopes and is locally continuous with flat-crested ridges of comparable surface texture characteristics that are not associated with upland slopes. Locally, the ledge-mare contact is marked by a narrow trench that floors below the mare surface. Variations in size and form of the mapped unit appear unrelated to the

steepness, height and irregularities of adjoining upland slopes.

These additional photogeologic "observations" extend the geologic analysis but unfortunately do not provide unique solutions. In many regions of the moon the upland areas are both more cratered and more sculptured than the surrounding mare surfaces suggesting that increased crater density as well as degree of sculpturing is a direct function of age, and of history related to repeated tectonic activity and constant infall of impacting bodies. In the Flamsteed area, the uplands are less cratered than the mare suggesting that they are younger--or seemingly in support of the ring dike intrusive hypothesis; on the other hand the sculpturing is greatest in the uplands suggesting the reversed age relations between upland and mare units.

One solution suggested to solve this apparent contradiction is that the upland ridges, though geologically older, retain fewer craters on their surfaces because of active slope processes that have progressively destroyed previously formed craters. Photogeologic evidence for this postulated process should be in the form of colluvial accumulations at the base of slopes and thus could be recorded in the Flamsteed area by the TMl unit.

However, colluvial deposits on the moon, as on the earth, should show direct relationships between size and shape of deposits and the characteristics of the slopes above them. The deposits should show up-slope extensions in gully-like or valley-like depressions and feather out in thickness on older deposits at their feet. In contrast the MTl unit shows no obvious size and shape relations to differing upland slopes and includes interconnecting flat-toped ridges that are not associated with highland slopes or with obvious supplies of detrital material. The MTl unit as mapped maintains a remarkably straight inner contact with higher slope materials of coarse surface texture, and is commonly separated from the mare by a steep frontal scarp locally associated with a trench that suggests a structural rather than colluvial contact relationship between ledge and mare. If the MTl unit is a colluvial deposit, it differs in significant aspects of form, shape, and slope relations from those associated with terrestrial colluvial deposits. It is possible that under the strikingly different, but little understood, lunar environment colluvial deposits could be developed that differ appreciably from common terrestrial forms. Nonetheless, the regional continuity of the MTl unit along the upland-mare contact, its bench or ridge-like forms, its seeming uniform elevation above the mare surface, and the suggestion of a structural rather than colluvial contact relationship with the mare indicate that a different interpretation may be in order. Using analogue reasoning, the author has suggested that the MTl unit may be a mare ledge, comparable to ledges left along the margins of lava pools and flows during phases of extrusion and solidification.

Although the photogeology of the Flamsteed region does not provide unequivocal geologic answers, it defines the types of problems that are present and directs attention to these areas and features on the ground, where observations and sampling by the astronauts will provide the critical geologic information needed to solve extant problems of interpretation. Once these have been resolved by ground observations, this information can be applied to photogeologic mapping of numerous other lunar areas characterized by similar features.

Suggested Geologic Traverses

In addition to the photogeologic definition of the geologic problems to be solved, scientific mission planning in the Flamsteed or other regions of the moon requires careful consideration of the modes of surface operations and instrumentation to be employed in satisfying the geologic objectives. Three types of missions are presently under consideration for lunar exploration: the scheduled Early Apollo (EA) type; and the proposed Apollo Applications Program (AAP), and Advanced Systems (AS) types. The ground support systems and scientific instrumentation components of these three mission types are under continuous research and design development, and will be revised as research and the surface exploration program proceeds. Ground capabilities and scientific instrumentation assumed in this paper for the three mission types are summarized in Figure 4.

Type of Mission	Support Shelter	Stay Time	Mode of Ground Travel	No. of Ground Excursions	Geologic Instruments	Data Package	Sample Return Capability	Geologic Objectives
Early Apollo	L. M.	1 - 2 days	Foot	2 - three hour excursions	Geologic hand tools & camera staff	1:100,000, 1:25,000 & 1:5,000 scale geologic maps to assist in location and traverse planning	80#	To determine the nature and origin of at least the upper 1 meter of mare material, the genesis and rock types associated with differing mare craters; and to return the greatest numbers and widest variety of samples of lunar material as possible.
AAP	LM/ Shelter with field laboratory	up to 14 days	LSSM with 8 km. operational capacity	1 - six hour excursion per day	Geologic hand tools & Lunar Surveying Staff; seismic, magnetic & gravity experiments on LSSM; petrographic microscope, X-Ray Fluorescence & X-Ray diffractometer in LM/Shelter	1:100,000, 1:25,000 & 1:5,000 scale geologic maps of general area and of sites along traverses of particular geologic interest	80-250#	To obtain detailed information regarding the major types of terrain on lunar surface including mare, highlands and major craters, to test the geologic interpretations based on Orbiter data and to obtain detailed data on rock composition, surface weathering features and structure.
Advanced Systems	L.M., & small lunar base with field laboratory when required for specific missions	at least 14 days and up to 90 days	"MOBEX" with at least a 200-400 km. operating capacity	one continuous-path traverse, or a series of traverses radially from small lunar base	essentially same as in AAP type missions	1:500,000 & 1:100,000 scale maps covering the area traversed and 1:25,000 & 1:5,000 scale maps for selected areas to be examined in more detail along the traverse	at least 250#	To provide a broad regionally integrated picture of the surface geology and crustal structure of the moon. The data obtained from these traverses are essential for full interpretation of data obtained from remote sensors carried on Lunar Orbiters or sensors placed on the surface by hard- and soft-landers, and also to tie together local detailed studies made during AAP surface missions.

Figure 4 - Summary of proposed post-Early Apollo scientific type missions as compared with Early Apollo Type missions.

The Early Apollo type mission, particularly during the first one or two flights, will be dominated by design consideration and operational problems involved in landing men on the moon and in returning them to earth. A restricted but highly significant scientific capability will be designed into the missions, however, which should satisfy primary scientific objectives of determining the nature and origin of mare craters and of at least the upper one meter of mare material, and to return for intensive laboratory studies the greatest number and widest variety of samples of lunar material as possible.

There are numerous potential Early Apollo landing sites in the Flamsteed Region. As an example one is located just south of the Surveyor I landing site in Figure 5. The character of the mare terrain in this selected site is shown in a Lunar Orbiter photograph enlarged to a scale of 1:5,000. At this scale, fields with boulders as small as three feet across, and craters as small as three feet across, are readily discerned. It is assumed that optimal traverse length by astronauts on foot will be about 1,000 feet out and back from the Lunar Module (LM). Actual traverses during the first missions may be much more restricted; much longer foot traverses may prove feasible during later Early Apollo missions. In the site selected, a sharp-rimmed crater about 300 feet in diameter associated with boulder fields and lineaments falls within the assumed range of ground observation, and would be a feature of prime geologic interest for sampling and observations.

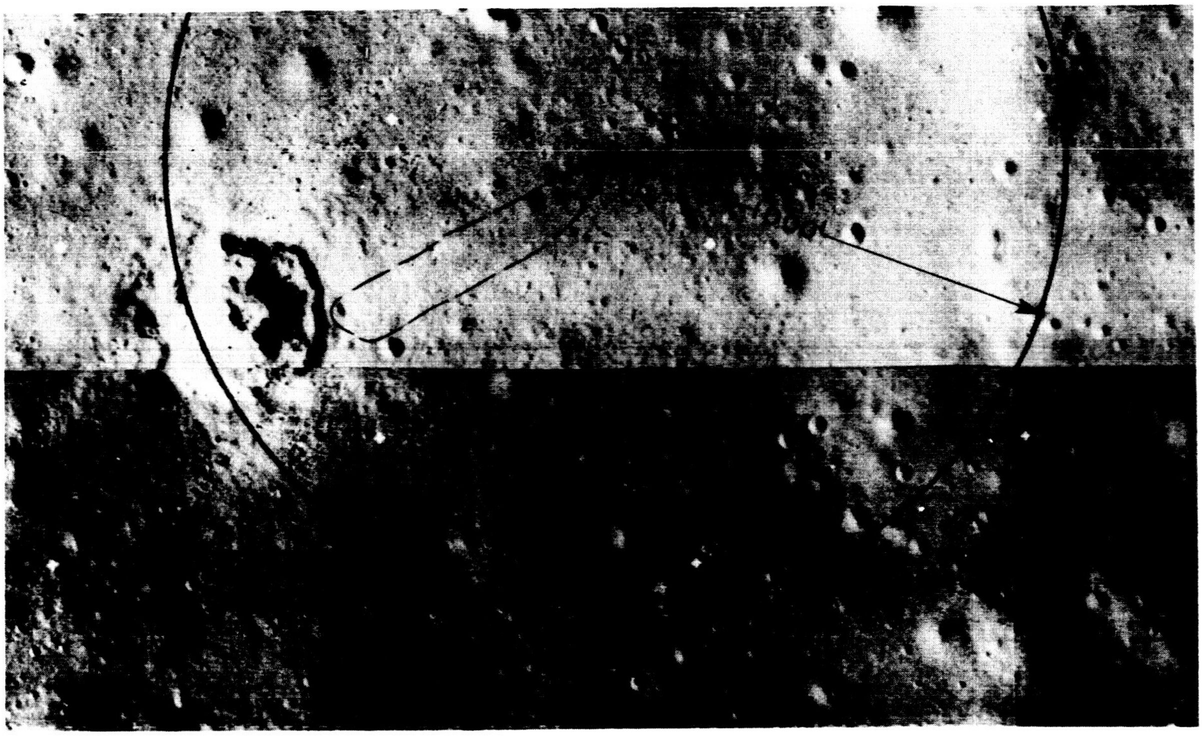

Figure 5. Enlarged Lunar Orbiter photograph (1:5000 scale) of a selected mare site in the Flamsteed Region just south of where Surveyor I landed. Dashed line illustrates an Early Apollo type of ground traverse. Location of site shown in figure 2.

Following the Early Apollo flights, it is expected that most of the operational problems will have been solved and that more ambitious scientific ground missions will be possible by the use of an augmented LM/Shelter and a ground vehicle that will permit stays up to 14 days and ground traversed within a radius of 8 - 10 kilometers from the LM/Shelter.

The geologic objectives of these more extended ground surveys would be to obtain detailed information on the major types of terrain on the lunar surface including mare, uplands, and large craters. Examples of Apollo Applications types of missions are shown in Figure 2. In both cases, the proposed missions are so located as to permit acquisition of critical data from the major features of geologic interest in the region, including the Terrae Uplands (Tu), Mare-Terrae Ledge (TMl), mare (DM), and mare ridges (Mr). In addition the AAP mission is the northern part of the Quadrangle would permit detailed mapping of a bright halo, rayed crater (X) and a larger sharp rimmed crater crossed by a mare ridge (Z) suggesting that mare ridge development was contemporaneous with, or postdated, crater formation. Both missions could define the rock types and stratigraphy of the terrae and mare units, establish critical contact relations, directly determine whether the MTl unit was of volcanic or colluvial origin, assess the weathering or depositional processes that have modified the mare and upland surfaces, and thus provide in broad outline the geologic history of the region.

Interpretations of the sub-surface structures inferred from the surface geology would be supported by seismic, gravimetric, and magnetic studies made in selected areas along the ground surveys. The field laboratory in the LM/Shelter would permit the trained astronauts to determine the mineralogical and compositional components of lunar field samples during the course of their field work. This capability would facilitate a more thorough analysis of the lunar geology, and permit the selection of only the most significant lunar samples for return to earth.

At a later stage of the surface exploration program, it is anticipated that a mobile laboratory will be developed that would permit much more extended ground travel on the moon. This two or three passenger vehicle would be a self-contained unit containing living quarters, laboratory facilities and instrumentation designed for trips across the lunar surface of at least 14 days duration and perhaps as much as 90 days. Two modes of ground traversing would be feasible. Loop traverses with one or more returns to the small lunar base, and extended path traverses originating at the landing area and extending to a predetermined area 200 - 400 km (perhaps as much as 1600 km) distant where a second space ship would land and return the astronauts and collected lunar samples to earth. The two Advanced Systems (AS) mission profiles shown for the Flamsteed region satisfy the major scientific objectives defining the composition, structure and contact relations of the major geologic units in the region. The 100 kilometer traverse provides a much more comprehensive and representative sample of the regional geology than would three or four Advanced Apollo type missions in the same region and probably at a more reasonable cost. The 290 kilometer AS traverse appreciably increases the amount of returned geologic information and would thus support a somewhat more detailed reconstruction of the regional geologic history. An extended path traverse of 270 kilometer as shown in Figure 1, however, could be expected to provide a still more representative ground sample of the regional geology by providing data points at four widely separate points along the Flamsteed Ring structure, more extended coverage of the regional mare surrounding the ring structure along with an adequate sample of the mare units filling the structure. In addition the 270 km path traverse would permit close examination of the large crater Flamsteed that occurs along the south end of the Flamsteed Ring, a study that could reveal critical geologic relations bearing both on large crater and ring structure origins. It would appear therefore that in the Flamsteed region the extended path traverse profile could offer distinct advantages over loop traverses in greater scientific returns per traverse mile.

A proposed Lunar Flying Vehicle (LFV) for AAP and later missions would greatly extend ground coverage by permiting observations of critical geological features inaccessible to foot and vehicular traverses. The LFV as presently envisioned (see Gordon Swann's paper) would also act as a rescue device during emergencies. As shown in Figure 2 side traverses made by the

LFV would allow close observations of stratigraphic relationships along steep upland scarps and in sharp rimmed craters.

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SCIENTIFIC MISSION PROFILES IN THE ALPHONSUS REGION

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EVALUATION OF GEOLOGIC SURFACE MISSIONS IN THE CRATER ALPHONSUS REGION

by

M. H. Carr and E. A. Holm

INTRODUCTION

The Alphonsus region of the Moon is of particular interest because of the reported "volcanic" activity within the crater. Traverses in this region will afford opportunity to check characteristics and relationship of various possibly volcanic dark halo craters to Alphonsus crater itself.

Structurally, a particularly well-defined zone of lineaments transects this crater. Its presence is apparent in rim, floor and central ridge structures. Other structural phenomena such as concentric, rim faults and faulting along rilles, clearly defined, afford opportunity to study the mechanics of crater development.

Stratigraphic relations of materials on the Alphonsus Crater, floor, and their relationship to the central ridge, and materials from adjacent craters Arzachel and Alpetragius afford valuable data on sequence of geologic events in the area.

Geologic investigation of this area will require use of long-range geologic laboratory, together with geophysical equipment adequate for geophone spreads over long-distance spans.

AAP MISSION IN ALPHONSUS REGION

AAP Missions Constraints: 14 days, 1-6 hrs/day, 1-2 men, 8 km radius, seismic, gravity and magnetic capability, shelter with pet. mike and X-ray fluorescence.

Site 1: Northeast quadrant of Alphonsus near the floor/rim boundary.

Lat. 12° 23'S, Long. 1°51'W (Fig. 1)

General Description: The center of the site is located close to the boundary between the level cratered floor of Alphonsus and the more rugged Alphonsus rim. It lies close to the dark halo crater Alphonsus MD and two well-rounded fresh appearing craters, 2. 2 km diameter and 1 km diameter respectively. A prominent rille passes through the dark halo crater and is intersected nearby by another major rille. The site is of interest in that several geologically interesting features occur in close proximity; fresh craters, subdued craters, dark halo craters, Alphonsus floor material, Alphonsus rim material, and linear rilles.

Tasks to be performed and to be incorporated into the mission plan:

1. Sample Alphonsus rim material.
2. Sample Alphonsus floor material.
3. Examine floor-rim contact - it is structural, does the floor material overly the rim material, is it a mass-wasting "flow" front, in what ways do the rim and floor materials differ in composition and texture, etc. ?

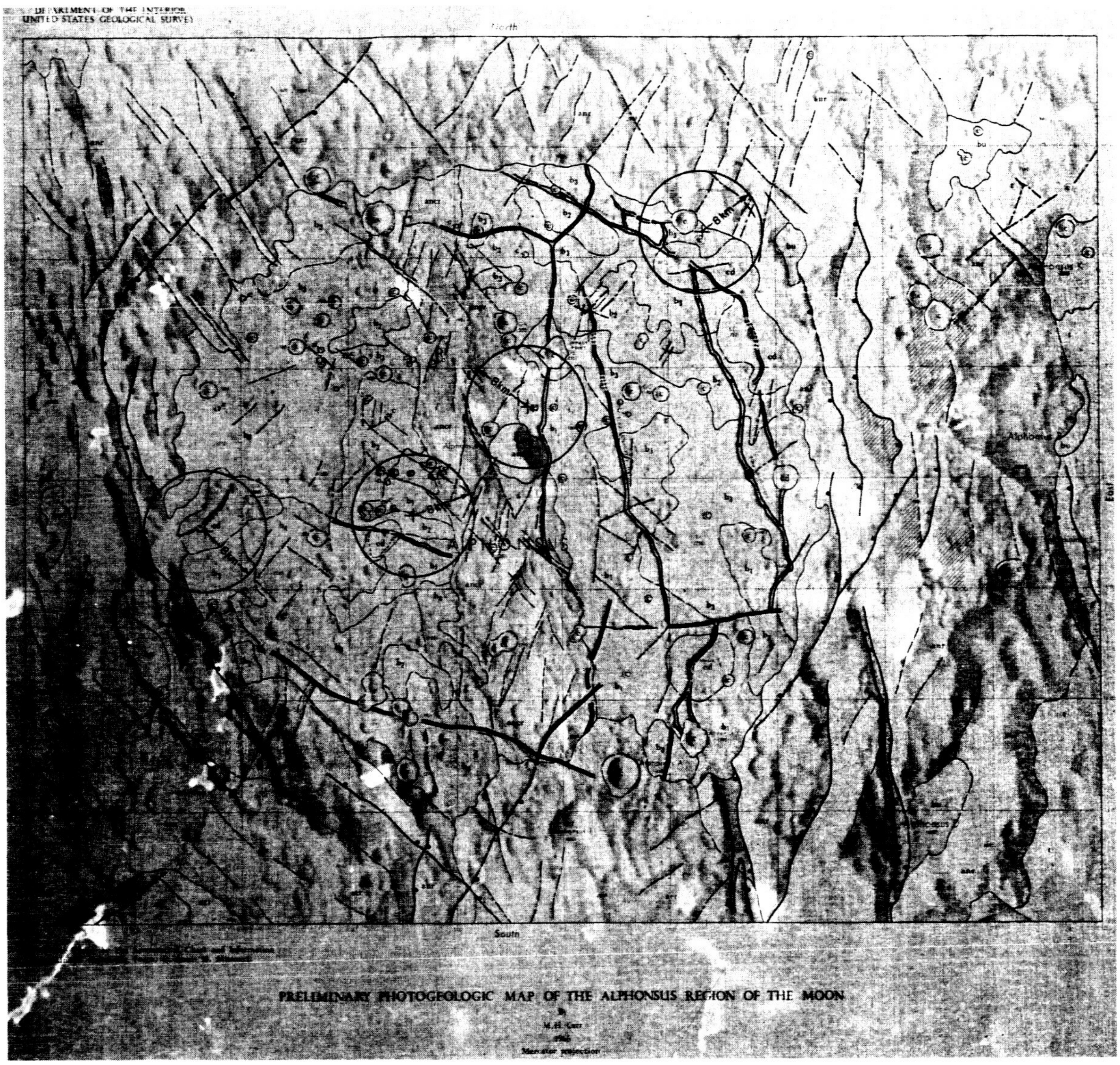


Figure 1. Sites for Apollo Applications Program in the Alphonsus Region.

EXPLANATION

c

High-rimmed crater material

Characteristics
Materials in and around craters with well defined, concave upward outer rims and sharp circular outlines. Intermediate to high albedo.

Interpretation
Impact crater materials. Brecciated and fragmented debris forms the rims, talus on the inner walls. Generally younger than the surrounding, more subdued craters.

cd

Dark halo crater material

Characteristics
Very low albedo material that occurs in and around craters that lie on rilles on the floor of Alphonsus. The craters with the dark haloe are commonly elliptical in outline, elongate in the direction of the rilles and have convex upward rims. The dark material extends as much as 5 km from the crater and fills adjacent depressions. The surface of the material is pitted with small craters ranging in size up to 50 meters in diameter.

Interpretation
Pyroclastic volcanic material in and around a maar-type volcano.

atr | atf | att

Alpetragius crater material

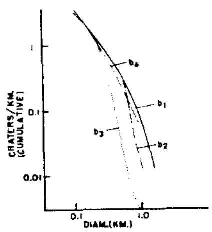
Characteristics
Subdivided into rim (atr), floor (atf), and talus (att) material. The rim material is difficult to distinguish from the adjacent Alphonsus rim material; however, the Alphonsus rim features are subdued in the vicinity of Alpetragius. The Alpetragius floor material has an intermediate to low albedo and includes a broad dome and some low hills. Talus material has a high albedo and occurs on the steep inner walls of Alpetragius.

Interpretation
Alpetragius is an impact crater, younger than Alphonsus. The crater is surrounded by a blanket of ejecta which partially masks the concentric ridges on the rim of Alphonsus. The talus is breccia on slopes close to the angle of rest, and the floor consists largely of slump material from the walls and brecciated bedrock.

bu | b_3 / b_2 / b_1 | b_4

Basin fill

Characteristics
Partly fills depressions. Generally level, heavily cratered terrain with intermediate albedo. Differentiated into four units on the basis of crater frequencies and surface topography. Crater frequencies indicated by the following figure.



Unit 4 is distinguished from the others by having numerous low ridges and hills on the surface. Faint linear ridges and depressions are discernible on the surface of all the units. These lineaments trend mostly NE and NW parallel to the structures in the Alphonsus rim and central ridge. Lines of intersecting disconnected craters also trend in these directions.

Interpretation
Largely volcanic debris reworked by successive impact. Analogous to mare material but older. Craters alined along lineaments may represent subsidence features on fault lines or old volcanic craters similar to the dark halo craters. Units 1 through 3 represent successively younger units. Unit 4 outlines an area where the basin fill is thin or in places absent and the underlying topography of the original floor of Alphonsus is apparent at the surface.

arr

Arzachel rim material (?)

Characteristics
Intermediate albedo. Generally smooth surface with low rounded ridges trending mostly NNE. Only sparsely cratered. Appears to fill other craters, Alphonsus J for example.

Interpretation
The designation as Arzachel rim material is doubtful. The material occurs close to Arzachel and covers and fills in other features and so could be ejecta from Arzachel. However, just south of the map area is a scarp separating the mapped area from obvious Arzachel rim material. Also to the east and west of Arzachel topographic expression of the rim material cannot be observed as far from the crater as the area mapped here. The unit mapped may represent a part of the Alphonsus rim that has been downfaulted, perhaps at the time of the Arzachel impact, and covered with a thin veneer of Arzachel rim material so that most of the surface relief is a reflection of the underlying modified Alphonsus rim.

Contact. Long dashes where approximate. Short dashes where dubious or inferred. Dotted where buried.

Fault. Bar and ball on downthrown side. Dashed where approximately located. Dotted where buried.

Linear depression or break in slope. Probable fault or fracture.

Linear ridge

anr

Alphonsus rim material

Characteristics
Forms the rim of the crater Alphonsus. Inward facing concentric scarps and ridges and depressions trending NW, NNW, and NE are the dominant topographic forms. Level areas relatively free of structures are indicated by ruled pattern. On top of many hills is a steeply sloping protuberance a few tenths of a kilometer across and with a slightly higher albedo than the surrounding terrain. A fine reticulate fracture pattern is discernible on all slopes. The unit is only sparsely cratered except in the delineated level areas.

Interpretation
Impact ejecta from the crater Alphonsus and uplifted bedrock. The near surface layer is probably fragmented debris formed largely by repetitive impact. The fragmental debris has slumped downslope, destroyed small craters and formed the reticulate fracture pattern observed on the slopes. Downslope slumping and crater destruction is probably continuing. Protuberances on top of positive features may represent areas where the fragmental layer is thin or absent.

ancr | ancp

Alphonsus central ridge
and central peak material

Characteristics
ancr, central ridge, similar to Alphonsus rim but lower relief. Has intermediate albedo. Low ridges and depressions trending NE and NW dominate the surface topography giving the ridge a herringbone appearance. Less cratered than the floor. The edge of the ridge, especially the western edge, is marked by a series of depressions. ancp, central peak, has a high albedo.

Interpretation
Central ridge is an uplifted portion of the original Alphonsus floor. Uplift caused by post-impact isostatic adjustment along the Imbrian faults. Depressions at the edge of the ridge are subsidence features along fault lines. During uplift movement also took place along pre-existing NW and NE trending fractures to give the ridge its herringbone appearance. Origin of the central peak is dubious. May have formed by rebound at the time of impact or during subsequent readjustment.

t

Regional terra material

Characteristics
Similar to Alphonsus rim but less relief and more heavily cratered. Topography dominated by ridges trending NNE radial to Mare Imbrium but the NE and NW trending fractures are also present. Larger craters (> 10 km diam) are mostly irregularly shaped with walls parallel to the principal structures.

Interpretation
Very old cratered and fractured terrain of indeterminate origin.

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4. Sample and examine the throwout from the fresh craters. Throwout represents material from below the surface, does this differ from the near surface materials? Is there evidence of inverse stratigraphy?

5. Sample and examine material from the inside walls of the fresh craters. Is "bedrock" exposed above the talus on the inner crater wall? If so is it stratified? What is the structure and texture, etc. ?

6. Examine and sample the rim of the dark halo crater Alphonsus MD. How does this material differ from the material from the fresh non-halo craters?

7. Examine the structural features of the rilles, especially at their intersection. Are there any features indicative of faulting evident at the surface?

8. Seismic work to determine the thickness of the floor material, the depth and dip of the rille forming faults, and structure of the bedrock underlying the floor material.

9. Magnetic survey to determine if the dark halo craters are fed by volcanic pipes and if an anomaly occurs in the region of the rilles.

10. Gravity survey to detect anomalies in the region of the rilles and dark halo craters.(Needs good topo control.)

Site 2: Center of the crater Alphonsus just north of the central peak.

Lat. 13°11'S, Long. 2°40'W

General Description: The center of the site is on the level cratered floor of Alphonsus close to both the central peak and the central ridge. A linear rille skirts to edge of the central peak, appears fresh close to the central peak but appears to be partly buried approximately 3 km north of the central peak.

Tasks to be performed and incorporated into the mission plan:

1. Sample Alphonsus floor material.
2. Sample Alphonsus central peak.
3. Sample Alphonsus central ridge.
4. Examine boundaries between central peak and floor, central peak and central ridge, central ridge and floor. Are the contacts structural or stratigraphic? What are the superposition relations?
5. Examine fresh craters, look for inverted rim stratigraphy and evidence of bedrock stratigraphy in the upper slopes of the inner walls.
6. Examine the rilles for evidence of origin - fault or flow structures-- and evidence of stratigraphy on the upper slopes of their walls. What is the nature of the material partially filling the rille just north of the central peak?
7. Seismic work to determine the thickness of the floor filling. Does the central ridge extend under the present floor filling? Is the edge of the ridge a fault contact and if so to what depth does the fault extend and what is its dip? Same for central peak.
8. Magnetic work to determine if the central peak and ridge each have an anomaly and if so what do the magnetics tell about the depth of each structure?

9. Gravity work for purposes similar to the magnetic work.

Site 3: Center of the floor of Alphonsus just west of the central ridge

Lat. 13°40'S, Long. 3°12'W

General Description: The site is located on a smooth floor unit close to a contact with a heavily cratered floor unit. Nearby are the central ridge, a rille, a dark halo crater and a linear ridge.

Tasks to be performed and incorporated into the mission plan:

1. Sample cratered floor unit and smooth floor unit and see if there is any difference between the two.
2. Sample material of the central ridge
3. Sample material forming the rim of the dark halo crater.
4. Examine fresh craters for inverted rim stratigraphy, exposures of bedrock on inner crater walls, composition of blocks, etc.
5. Do same for dark halo craters and compare with fresh non-halo craters.
6. Examine contact between floor and central ridge of Alphonsus. Is this a structural or stratigraphic contact, if stratigraphic what are the overlap relations?
7. Examine rille that passes through the dark halo crater. Is there any evidence of faulting at the surface? Is bedrock exposed on the walls?
8. Run seismic profiles to determine the thickness of the floor filling of Alphonsus, to determine if the central ridge material

extends under the floor units presently exposed at the surface and to determine the dip of the faults possibly forming the rilles and the possible faults at the contact between the floor units and the central ridge.

9. Run magnetic survey to see if any anomalies are present. If anomalies occur around the rilles, dark halo crater and central ridge, what are the depths of the anomalies?

10. Gravity work to supplement 9.

Site 4: Western edge of the crater Alphonsus.

Lat. 13°44', Long. 4°10'W

General Description: This site lies on the floor of Alphonsus close to its western contact with the Alphonsus rim material. Also present in the site area are a dark halo crater, a rille, a smooth floor unit and the Alphonsus floor unit having the most relief.

Tasks to be performed and incorporated into the mission plan:

1. Sample both the smooth floor unit and the rough floor unit. Are there compositional differences between the two?

2. Sample Alphonsus rim material.

3. Examine the contact between the floor and the rim. Is the contact structural or stratigraphic; if stratigraphic what are the overlap relations?

4. Sample the dark-halo rim material and examine the texture and lithology of the rim material.

5. Examine the rille to determine if evidence of faulting is present at the surface.

6. Examine fresh craters for inverse stratigraphy on rims and bedrock on inner walls.

7. Seismic work to determine to thicknesses of the two floor units. Is the rough floor unit merely the original floor of the crater exposed at the surface or does it represent a part of the floor where the filling is unusually thick? Can the contact between the filling and the rim be followed under the present surface? What are the dips of the faults that form the rille?

8 Magnetic and gravity surveys to detect anomalies and their depths. Is there a volcanic pipe under the dark-halo crater? Is there an anomaly under the rille?

ADVANCED SYSTEMS MISSION IN ALPHONSUS REGION

General objectives in the area should incorporate the following tasks:

Samples should be taken of all the floor units, the central ridge, the central peak, the rim of Alphonsus, the rim of Alpetragius, the talus on the inner wall of Alpetragius, the central mound of Alpetragius, the mare material to the west of Alphonsus, the blanketing material covering the southern rim of Alphonsus (Arzachal rim material?), dark-halo crater rim material, rim materials from very fresh bright halo craters and if possible material from in and around the crater chain in Davy Y. Samples should be taken on the inner walls of craters to get vertical sections as well as horizontal distribution. Cored samples would be especially useful on the rims of large craters where inverted statigraphy occurred, because it could give clues concerning composition of material at considerable depths.

Geologic contacts should be examined critically for evidence of overlap relations and structural discontinuities. Of particular stratigraphic importance are following contacts: Alphonsus central ridge/all four types of Alphonsus floor material, Alphonsus central peak/Alphonsus central ridge, Alphonsus central ridge/rilles, Alphonsus central peak/Alphonsus floor, and Alphonsus central peak/rille, Alpetragius rim/Alphonsus rim, Arzachel rim/Alphonsus rim, Alphonsus rim/mare material, Alpetragius rim/mare material.

Seismic data should be analyzed for thicknesses of geologic units and subsurface structures of particular importance are: the thicknesses of the floor material in Alphonsus; the presence or absence of breccia lenses beneath Alphonsus and Alpetragius and the thickness of these lenses; the thickness of the mare material west of Alphonsus and deep subsurface discontinuities. Seismic work should also be directed toward determining the vertical profiles of the faults bounding the rilles and possible faults at the contact between the central ridge and floor in the crater Alphonsus and along certain lines of craters such as the one in the floor of Alphonsus at 13°40'S, 2°12'W and the one in Davy Y.

Magnetic and gravity measurements should be made to locate anomalies. Of particular importance are anomalies associated with rilles, dark-halo craters, and the central peak and ridge of Alphonsus. The shape of the anomalies, if any, would indicate the depth to which these structures extend and the magnitude of the anomalies should give important information on compositional differences beneath the surface. The anomalies around craters may indicate whether the craters are of impact origin or are the surface expression of some feature, such as a volcanic pipe, that extends well below the crater.

ADVANCED SYSTEMS MISSION TRAVERSES IN ALPHONSUS REGION

(See Figure 2)

LM BASE

Location: Central Peak, Alphonsus Crater; base located at latitude 13°36'S; longitude 2°24'W, 8 km SE of Central Peak. This locale:

1. provides central location for originating research traverses
2. permits study of geologic relationships in the immediate vicinity of Alphonsus peak, ridge, floor and rille bordering peak on east.

DATA wanted and studies to be made in vicinity of LM Base:

1. Samples (▲) collected, described and petrographic studies made of:
   a. Alphonsus floor material (Bl, type)
   b. Central peak material and
   c. Central ridge material
   d. materials across rille at:
      (1) contact between central peak/rille
      (2) contact between central ridge/rille
2. Geologic study ( ) of phenomena occurring at contact between:
   a. Alphonsus central ridge material and Alphonsus floor material (Bl type)
   b. Alphonsus central ridge material and Alphonsus central peak material

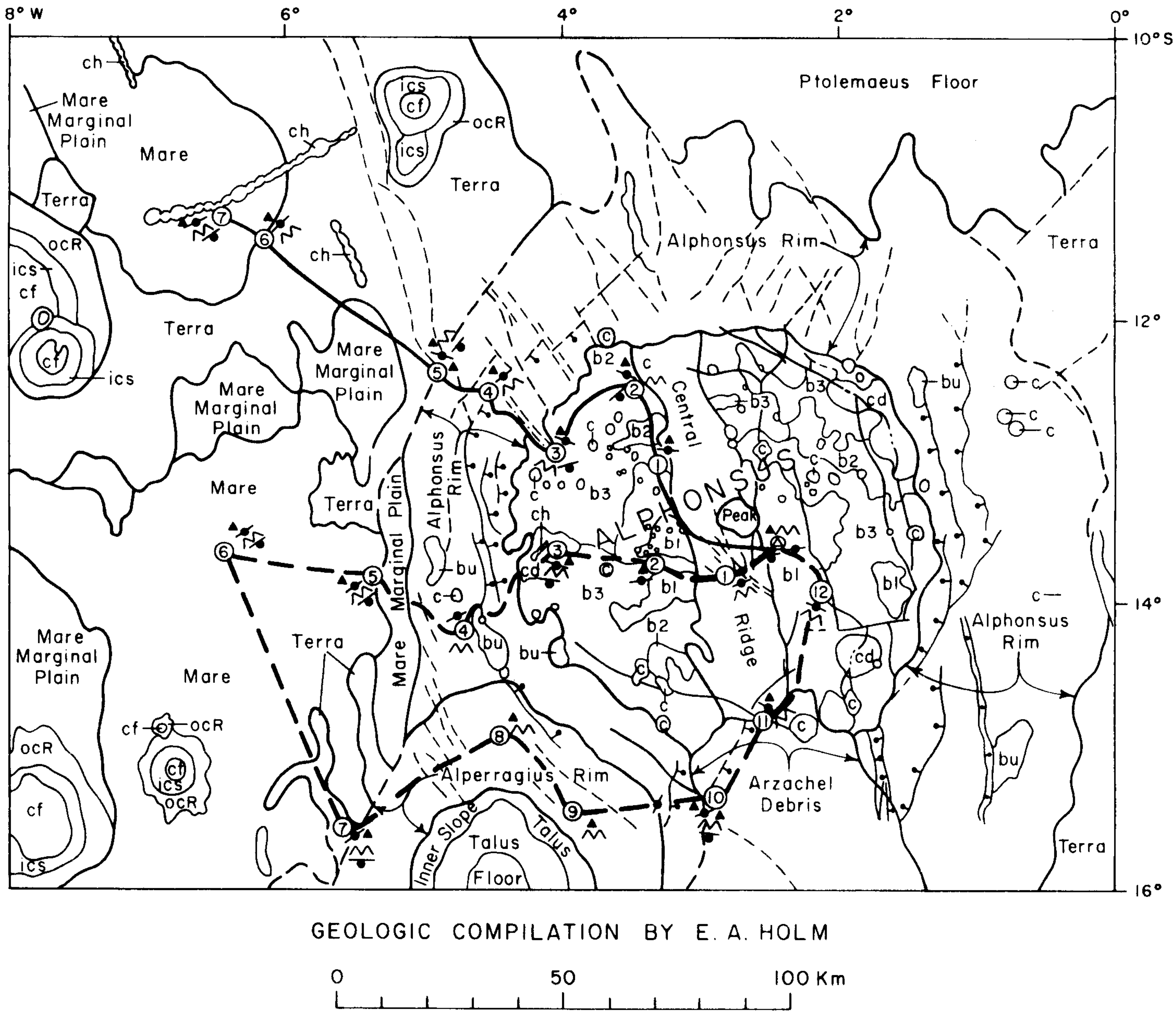

Figure 2. Advanced System Mission traverses in the Alphonsus Region.

EXPLANATION

Advance system traverses

LM Base

Traverse 1

Traverse 2

Station number

Sample collection

Geologic contact study

Seismic data needed

Gravity data needed

Terrain

b1, b2, b3, b4, bu - Floor

material types in Alphonsus crater

ics	Innerslope of crater
ocr	Outer rim of crater
cf	Crater floor
c	High rim crater; sharp outline
ch	Chain crater
	Rilles
	Lineament
	Fault bar ball downthrown side

c. Alphonsus central peak materials and rille materials

d. Alphonsus central ridge materials and rille materials

e. Alphonsus central ridge material in lineament zones

3. Seismic study ( ) shot line originating on ridge and extending to peak, to rille and to B1 floor deposition in order to determine:

   a. thickness of Alphonsus floor formation (type B1)

   b. subsurface relations between central ridge, central peak, rille and floor

4. Gravity study ( ) along traverse line similar to above seismic line to determine possibility of gravity anomalies associated with:

   a. rille

   b. Alphonsus central peak

   c. Alphonsus central ridge

TRAVERSE 1

Two-hundred kilometer (200 km) traverse from LM Base along west side of central ridge northward to crater rim; southwestward and onto rim crest; hence NW descending from rim to terra surface and continuing northwestward to large chain crater in mare material. Seven observation stations to be established--observations to be made between stations wherever deemed necessary. Station location, studies required and observations to be made as follows:

Station 1: Latitude 13°S; longitude 3°12'W. Within 3 km radius of this site are Alphonsus central ridge, crater floor formations type 3 and type 2, and several high-rimmed craters.

DATA wanted and studies to be made:

1. Samples (▲) collected, described and petrographic analysis of

   a. Alphonsus floor material (types B2 and B3)

   b. Alphonsus ridge material

   c. high rim crater materials from:

      (1) inner slope

      (2) outer slope

      (3) rim crest

   d. at contacts (if any changes in rock characteristics are observed)

      (1) between floor material type 2 and 3

      (2) between central ridge materials and floor material type 2 and floor material type 3

Station 2: Latitude 12°26'S; longitude 3°28'W. Within 5 km radius of the site are: large high-rim crater, 4 km in diameter, lineament (fault?) scarp along margin of central ridge, Alphonsus rim area and types 2 and 3 crater floor material.

DATA wanted and studies to be made:

1. Samples (▲) collected, described and petrographic analysis

made on:

a. Alphonsus floor material (type B2, type B3)

b. Alphonsus rim material

c. Bright crater material from

(1) crest

(2) inner slope

(3) outer slope

d. materials within lineament (fault) zone

2. <u>Geologic study</u> ( ):

a. along lineament scarp between floor material B2 and central ridge

b. between floor type B2 and B3

c. between floor types B3/B2 and central ridge rock

3. <u>Seismic study</u> ( ):

a. across lineament (fault?) scarp between floor material B2 and central ridge

b. across high-rimmed crater on central ridge material

c. set up shot control center for traverse from Alphonsus crater floor to Alphonsus crater rim. Shot line for study to provide data on depths of floor materials and relationship between Alphonsus crater floor and and Alphonsus crater rim

4. Gravity study ( ) for magnetic anomalies:

   a. across high rim crater, crater floor material B2 and central ridge

   b. across lineament scarp between central rim floor--central ridge

Station 3: Latitude 12°52'S; longitude 4°W. At base of high, rough NW sector of Alphonsus rim which in this area is intersected by a 10 km wide zone containing NW-trending lineaments (part of one of the major lineament zones on the lunar surface. Two of these lineaments border a tongue of the Alphonsus rim which projects into crater floor.

DATA wanted and studies to be made:

1. Samples ( ) collected from:

   a. Alphonsus rim material

   b. Alphonsus crater floor material

   c. Samples from both these formations where cut by lineaments

2. Geologic study ( ) of contacts along lineament zone for evidence on fault pattern and sequence of faulting

3. Seismic study ( ) across lineament zone along contact with crater floor to determine vertical profiles on faults and location and direction of discontinuity surface between crater floor and crater rim

4. Gravity study ( ) along same zone to determine anomalies between crater rim and floor

COMMENTS:

Traverse from Station 3 to Station 5 across Alphonsus rim will be slow and difficult; suggested route from Station 3 to Station 4 is along crest of lineament scarp to high point in rim, then around large crater westward to Station 4 on lower ridge crest on outer rim of crater. Traverse from Station 4 to Station 5, also will be slow and difficult because Alphonsus rim material masks underlying faulted and fractured terra material. Relief on traverse from Alphonsus crater floor to higher points on rim may be as much as 650 m $\pm$.

Station 4: Latitude 12°30'S; longitude 4°3'W. Crest of outermost and possibly lower secondary rim of Alphonsus, along southwest margin of lineament zone. Elevation station possibly 400 m $\pm$; relief above crater floor on this sector of traverse from 750 to 220 m. Station 4 situated on ridge between two probable faults, part of a group of concentric faults, associated with the crater rim both faults are downthrown on side toward the crater floor.

DATA wanted and studies to be made:

1. Samples (▲) collected from rim material:
   a. at various places along traverse between Station 3 and Station 4
   b. in fault and lineament zones

2. Geologic study ( ) of fault pattern, their relationships in the rim area; NW lineaments and concentric faults intersect near this station

3. Seismic study ( ):

   a. of faulting in area

   b. to establish another seismic base for continuing the line traverse to Station 7 crossing outermost crater rim and old terra formations in order to determine:

      (1) existence of possible deep surface discontinuity between mare and terra

      (2) depth of terra formations

4. Gravity study ( ): if deemed advisable

Station 5: Latitude 12°10'S; longitude 4°55'W. Contact between outermost Alphonsus crater rim and terra materials. Marked change in terrain from rough crater rim to rolling crater-pitted terrain which merges westward into a mare-marginal plain with very slight relief; continuing to northwest, traverse crosses onto gently rolling terra. Data collection may be continued along traverse to Station 6.

DATA wanted and studies to be made:

1. Samples ( ) collected from:

   a. Alphonsus rim material near outermost edge

   b. terra material

      (1) near rim and up to 2 to 3 km to west of rim

(2) from mare-marginal plain

2. Geologic study ( ) phenomena at contact:

   a. between outermost crater rim material and low terra material and along traverse westward

   b. between low terra material and mare-marginal plain forming materials

3. Seismic study ( ):

   a. of above contacts to determine presence of disconformities between terra and mare-marginal plain

   b. continue net begun at Station 4

4. Gravity study ( ) at same points to discern presence of possible anomalies between terra and border mare areas.

Station 6: Latitude 11°28'S; longitude 6°10'W. Traverse crosses from terra onto mare plain which is trenched midway of its extent by a very long deep chain crater.

DATA wanted and studies to be made:

1. Samples ( ) collected and described from:

   a. terra material

   b. mare-like material

   c. terra material/mare material contact

2. Geologic study ( ) at terra/mare-like contact

3. Seismic study ( ) carried from Station 4 onward to Station 7

Station 7: Latitude 9°11'S; longitude 6°32'W. Located at the margin of a chain crater complex 58 km long, which trends east and northeastward across the floor of very gently rolling mare onto the terra. Craters from less than 500 feet to 2 miles in diameter are aligned along the complex.

DATA wanted and studies to be made:

1. Samples (▲) collected and described:
   a. from mare-marginal formation (Icy) at margin of crater chain
   b. from crater rims and walls, if possible to secure samples
2. Geologic study ( ) contact:
   a. along crater chain. mare-marginal material is in contact with crater chain material to determine degree of alteration in former material
   b. to determine nature of crater origins
3. Seismic study ( ):
   a. across crater chain
   b. along portion of crater chain for 5 to 10 kilometers to determine relation between chain of craters and adjacent materials either terra or mare-marginal type
4. Gravity study ( ) along same lines as Seismic study;

to check for presence of gravity anomalies in vicinity of chain craters.

TRAVERSE 2: (fig. 2)

Time precludes setting up a traverse descriptive manual similar to that for Traverse I. However, twelve observation stations are located on this traverse (fig. 2) at each of which the type data to be collected is indicated on map by a symbol or group of symbols. Lines indicating arrangement of seismic and gravity nets designate areas where subsurface data is needed to determine geologic, stratigraphic and structural relationships. This traverse, some 350 - 400 km in length, extends from LM Base due westward crossing in seccession Alphonsus central ridge (Sta. 1), members b_1 and b_4 of Alphonsus crater floor formation (Sta. 2), a large group of dark halo craters (Sta. 3) to ascend the inner slope of Alphonsus crater rim (Sta. 4). The latter is steep, and rises in succession across three concentrically aligned faults, each downthrown on the crater side. An extensive area of crater floor formation undefined as to type (Sta. 5), lies on outer slope just below rim crest.

From crest of crater rim (Sta. 5) traverse descends westward, across mare terra formations to terminate on an extensive area of mare (Sta. 6). From this westernmost station, the traverse continues southeastward to the contact between mare and outer slopes of crater, Alpetragius (Sta. 7); hence northeastward to a station where outer slopes of Alpetragius and Alphonsus impinge on each other (Sta. 8). From this point traverse ascends outer slopes of Alpetragius crater to the rim (Sta. 9); traverses along rim to point where Alpetragius outer slope materials lie adjacent those of Arzachel crater materials (Sta. 10). From this point, traverse turns northeastward descending to Alphonsus crater floor across an extensive area of Arzachel debris which lies within the southern end of Alphonsus crater and, borders the Alphonsus central ridge as well as various types of crater floor materials (b_4, b_3 and bu_2 types) (Sta. 11). A high rim crater 5 km in diameter is about 5 km to east from Sta. 11. Traverse returns to LM Base along east side of Alphonsus central ridge affording observation of several rilles in which walls are apparently fault scarps (Sta. 12).